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Dose/Surface Charging and Plasma Monitor (DOS/SCM) Flight Model 2—HiLET Subsystem Critical Design Review

10 April 2004

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Michael Zambrana
SMC/AXE

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14. ABSTRACT

This report documents the critical design review for the High Linear Energy Transfer (HiLET) instrument subsystem of the Dose/Surface Charging and Plasma Monitor Flight Model 2. The design review took place on 15 January 2004 at The Aerospace Corporation, El Segundo, CA.

15. SUBJECT TERMS
Surface charging, High LinearEnergy Transfer

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Dose/Surface Charging & Plasma Monitor (DOS/SCM) Flight Model #2

HiLET Subsystem Critical Design Review

15 January 2004

Opening Remarks

Joe Mazur
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Purpose & Scope of CDR

- Presentation & status of HiLET (High Linear-Energy Transfer) sensors
- Unclassified
- Review covers
  - HiLET sensors
  - Attendant changes to DOS/SCM
- We invite the audience to submit Recommendation For Action (RFA) sheets
  - Assessment of readiness for construction of HiLET flight hardware & software
  - Any other topic of interest or concern
  - Point of contact for RFAs: Christine Camacho

CDR Agenda

Timing by main topic

Start time	Duration (min)	Section #	Topic	Presenter
0800	5	01	Opening remarks & introduction	Joe Mazur
0805	30	01	FM2 goals & objectives	Joe Mazur
0835	10	02	Project management & schedule	Christine Camacho
0845	40	03	System engineering	Bill Crain
0925	15	04	Mechanical design	Albert Lin
0940	40	05	Structural analysis	Enold Pierre-Louis Michael Van Dyke
1020	15		Break	
1035	10	06	Detectors	Joe Mazur
1045	30	07	Electronics design	Bill Crain
1115	20	08	Flight software	Dan Mabry
1135	20	09	Test program	Bill Crain
1155	15	10	Project programmatics	Christine Camacho
1210	5	11	Closing remarks	Joe Mazur

CDR Checklist

- The HiLET CDR will demonstrate:
  - Understanding of performance and interface requirements
  - Understanding of mission environment
  - Risk management processes
  - Understanding of reliability & workmanship policies & application
  - Adequacy of design concept & implementation
  - Adequacy of technical resources (mass, power, volume)
- The HiLET CDR will specify our approaches to:
  - Long-lead items
  - Radiation
  - EMI
  - Pressure venting
  - ESD sensitivity & precautions
  - Handling

Project Review History

- Project Initiation Management Review 4/17/2003
  - This was an Aerospace internal review
  - Covered the total FM2 project management structure & funding
  - Result: project go-ahead
- No CoDR or PDR due to tight schedule

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FM2 Goals & Objectives

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Aerospace HEO Investigations - the Beginning

- Between 1983 and 1989 Aerospace, with the help of Sandia colleagues, measured the dose in HEO orbit under 100 mils of aluminum with a simple, single channel, slab-geometry sensor. Two flights were made.
- The series of observations indicated that: "...the AE-8 model substantially over-predicts the dose received in a HEO orbit under ... 100 mils of aluminum."
  - *J. B. Blake and J. E. Cox 1989, AIP Conference Proceedings 186, AIP, New York.*
  - *J. B. Blake 1990, ESA Workshop Proceedings WPP-23, Noordwijk*

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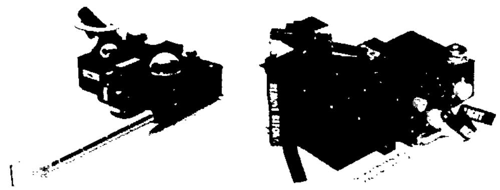
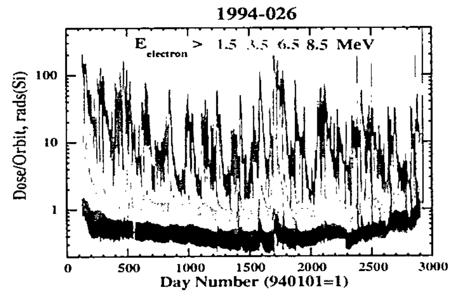
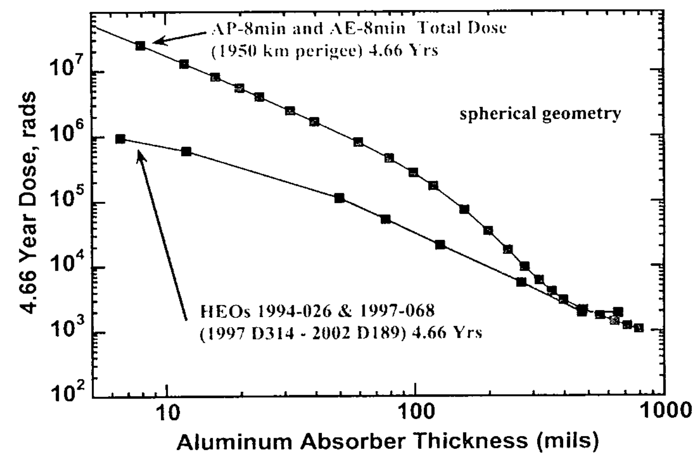
Further Investigations of the HEO Environment

- 1994-026
  - 4 dosimeters, solid-state detector telescope, & magnetometer
- 1995-034
  - 1 dosimeter, telescope, plasma analyzer, & dual magnetometers
- 1997-068
  - 4 dosimeters & solid-state detector telescope





HEO Observations Versus Universally Used Models



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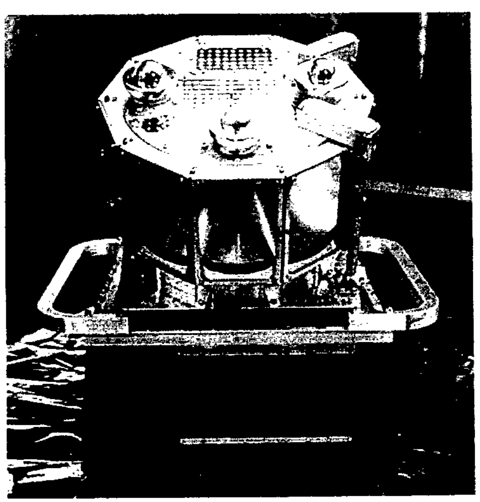
DOS/SCM FM1



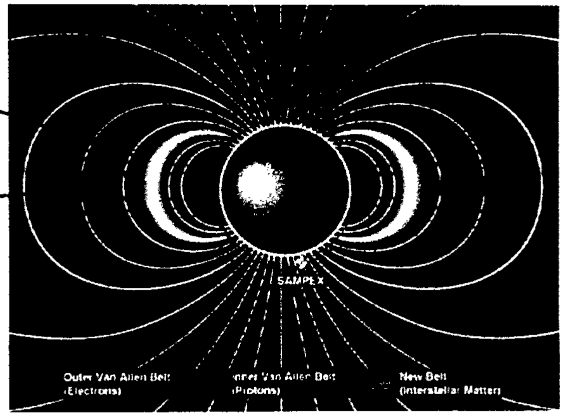
- Measurements:
  - Electrons
    - 10 eV to 30 keV
    - >300 keV, 1.4 MeV, & 2.5 MeV
  - Protons
    - 10 eV to 30 keV
    - >8, 15, & 26 MeV
  - Dose under 11 mils Mg, 49.5, & 126 mils Al
- Delivered November 2002
- Currently in calibration & test
- Redelivery February 2004

FM2 Project Goals and Objectives

- Goals
  - Modify FM1 design to provide energetic ion spectra for improving decades-old environment models, to support solar array design, and to improve SEE specification & prediction
    - Responding to evolving interests of Aerospace customers (in particular, MEO orbits)
    - To be done within spacecraft resources allocated to FM1
  - Deliver flight-worthy FM2 to TWINS-2 host in FY04
- Primary Objectives
  - Fabricate, test, and calibrate the SCM
  - Develop, fabricate, test, and calibrate the High-Linear Energy Transfer ion Telescope (HiLET)

Environment Issues: New Radiation Belts

- **Transient radiation belts due to**
  - **Anomalous cosmic rays**
  - **Shock-injected particles during intense solar proton events**

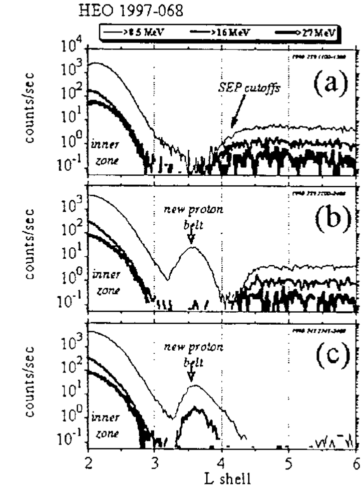


Environment Issues: New Radiation Belts

•No radiation models adequately specify new belts that are shock-related

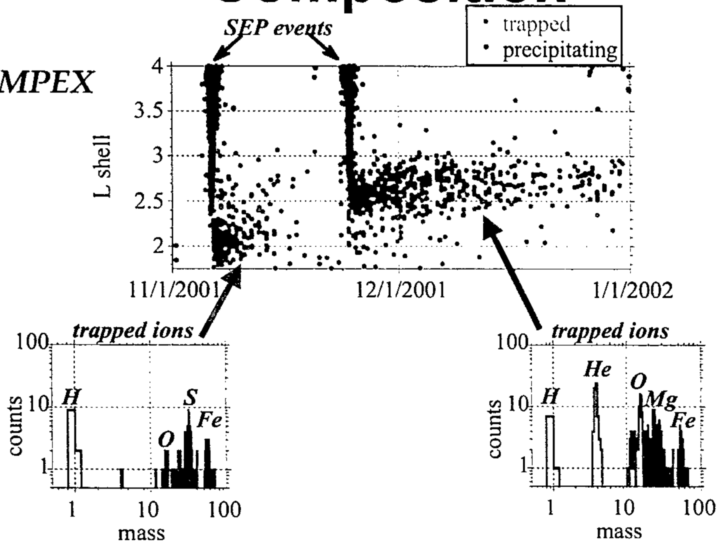
•Several processes may be responsible for their creation.

•Their properties have only been glimpsed with recent missions (*e.g.* 24 March 1991 observed with CRRES, Blake *et al.* 1992; Li *et al.* 1993).

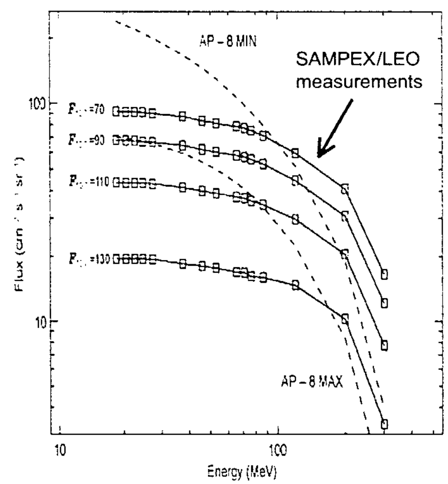


-example of a new belt that formed after the shock/SEP event of 24 Aug. 1998

New Belts: Variable Heavy-ion Composition



Proton energy spectra - discrepancies with AP-8



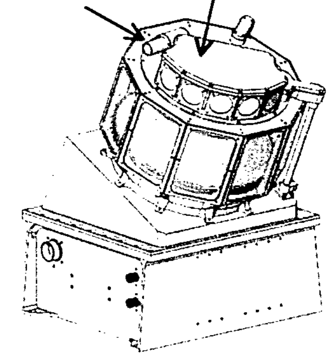
- **Observed proton spectra in the inner zone are markedly different from model**
- **CRRES observations (< 100 MeV) also showed flatter proton spectra**
  - **Analysis difficult with large corrections necessary - illustrates difficulty analyzing inner zone measurements**
  - **Gussenhoven et al. 1993, Trans. Nuc. Sci. 40, 1450**

Breakdown of DOS/SCM FM2 Requirements

FM2 project requirement	SCM	HiLET
Provide measurements of the space environment that directly relate to:		
surface charging	✓	
surface dose	✓	
penetrating radiation		✓
total dose		✓
radiation belt dynamics	✓	✓
Provide direct environmental support to the host vehicle	✓	✓
Gather data needed to develop environmental models and specifications for future programs	✓	✓

HiLET

- HiLET uses particle-detection and analysis techniques that are similar to sensors flown on previous HEO missions, but HiLET is much more capable
- Uses new technologies developed for NASA/STEREO mission
  - Caltech PHASIC 16-channel amplifier chips (3)
  - Micron Semiconductor Ltd. solid-state detectors
- Caltech support to HiLET verified in meeting with Prof. E. Stone & SRL staff on 3/25/2003
- Project continues long-standing Aerospace collaboration with space scientists at Caltech & JPL



HiLET Requirements - 1

HiLET heavy-ion telescope parameter	Performance requirement	Motivation
Geometric factor	>1 cm^2sr	Due to falling spectra, need large geometry factor to get sufficient statistics at highest LET
Energy range (MeV/nucleon)	3 - 70 (Z = 26)	Threshold as low as possible for analysis of surface effects; maximum energy to penetrate at least 80 mils Al.
Particle species measured	$6 \leq Z \leq 26$	No light-ion analysis to provide Immunity from pile-up & high dead-time in radiation belts
FOV	Wide acceptance (>45 degrees)	Includes perpendicular pitch angles at low-L without detailed pointing requirements
Mass resolution (sigma amu)	<0.5 amu (elemental resolution)	Largest contributions to LET spectrum come from most abundant, even-Z elements
Event analysis rate	20 events/sec	Telemeter all $Z \geq 6$ ions in 7/14/2000 SEP event

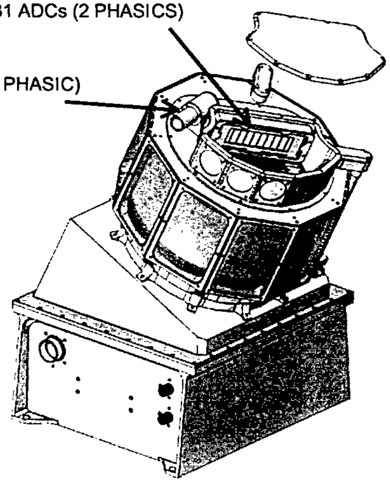
HiLET Requirements - 2

HiLET proton telescope parameter	Performance equirement	Motivation
Geometric factor	10^{-2} to 10^{-3} cm^2sr	Sufficient for peak intensities in radiation belts & SEP events
Energy range	6-20 MeV (protons)	Proton ranges ~10-100 mils Al
Particle species measured	Protons (wth goal to include alphas and ~0.5 MeV electrons)	Highest range; continuity with previous SSAL measurements of ~0.5 MeV electrons in outer zone
FOV	Collimated aperature; overlap with HiLET ion telescope	Minimize scattering of electrons into FOV; simultaneous FOV coverage of all ion species
Event rate	Onboard collection of ≥ 8 spectral bins, one spectrum per second	Sufficient for proton spectrum in inner zone
PHA events	Periodic transmission of full PHA events	Ground-based check of on-board binning

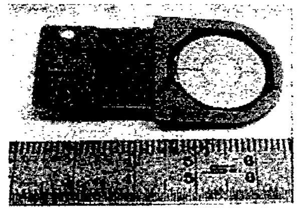
HiLET Major Components

Heavy ion sensor:
8 detectors, 31 ADCs (2 PHASICS)

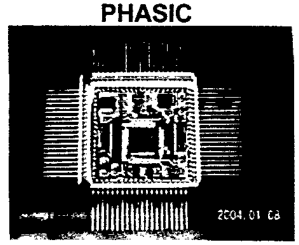
Proton sensor:
4 detectors, 4 ADCs (1 PHASIC)



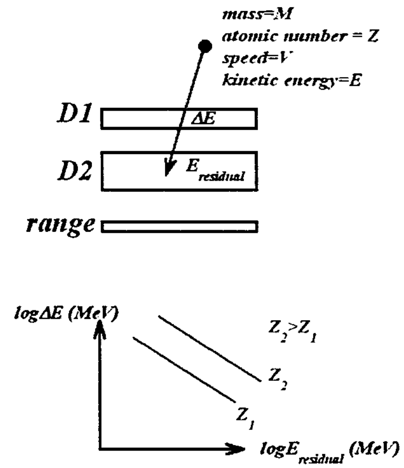
L1 detector



PHASIC



HiLET Measurement Principle

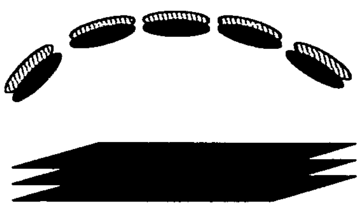


$$\Delta E \approx \frac{dE}{dx}\Delta x \propto \frac{MZ^2}{E}\Delta x$$

$$E\Delta E \propto MZ^2$$

HiLET Detector Stacks

Heavy-ion sensor



6 µ ITO/Kapton/Al foil (x5)
20 µ 2 cm² (x5)

50 µ 10.2 cm²
1000 µ 15.6 cm²
1000 µ 15.6 cm²

Proton sensor

300 µ 0.4 cm²*
300 µ 0.4 cm²*
1000 µ 0.5 cm²
1000 µ 0.5 cm²

*20000 Å Al solar-blind window

Representative energy ranges:

- **Oxygen: 2.7-40 MeV/nucleon**
- **Protons:6.5-18.5 MeV**
- **Electrons: 0.25-1.2 MeV**

Project Management & Schedule

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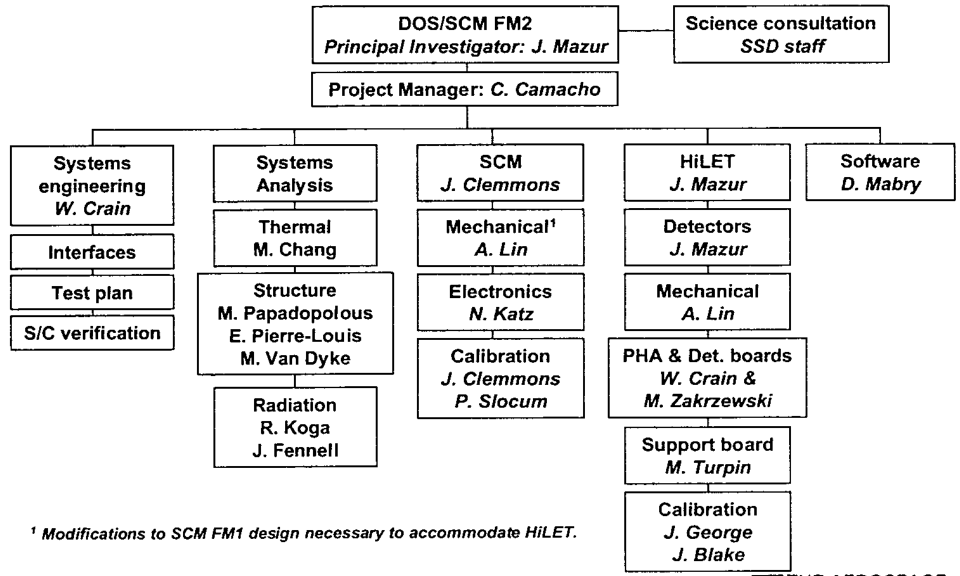
Project Organization



[1] *Modifications to SCM FM1 design necessary to accommodate HiLET.*

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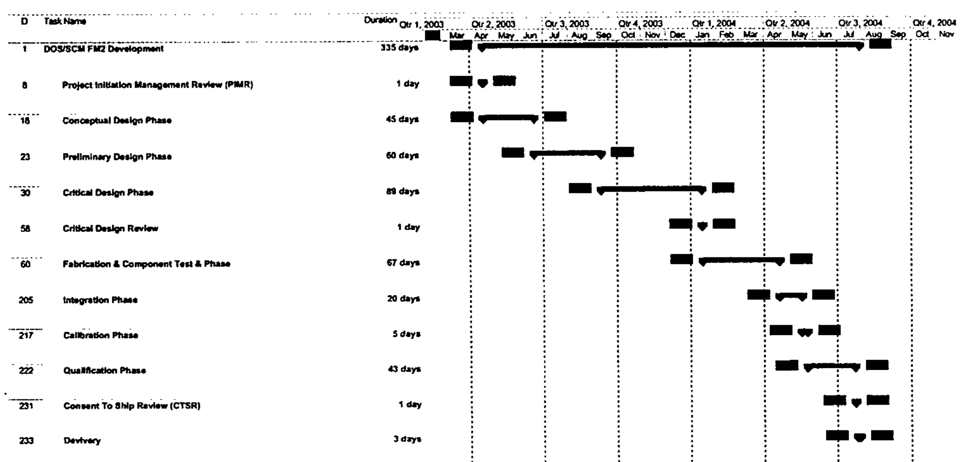
DOS/SCM FM2 Schedule



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System Engineering

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Overview

- Changes to FM1 and Impact Assessment
- Requirements Flowdown
- Concept of Operations
- Power and Mass Reserves
- Documentation
- Contamination, Safety, and Handling
- EMI Design
- Thermal Design
- Radiation & Charging Mitigation
- Summary

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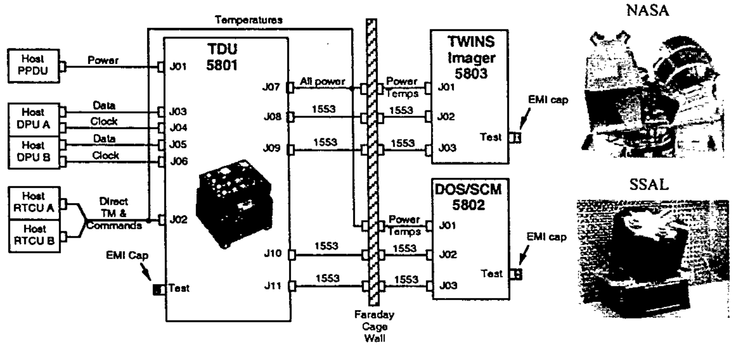
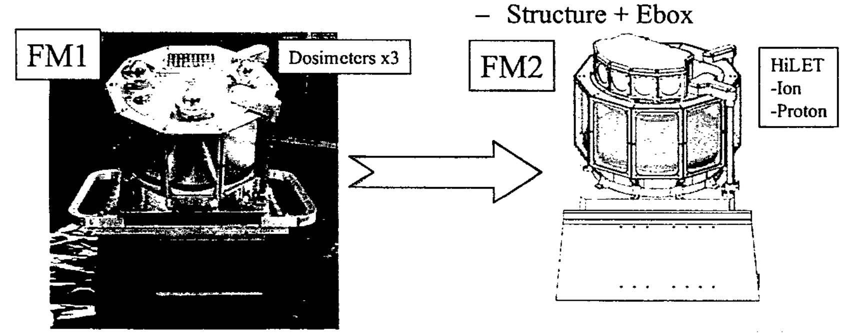
Payload Configuration

- DOS/SCM is part of the TWINS/ES payload
- Interface to S/C is through TDU

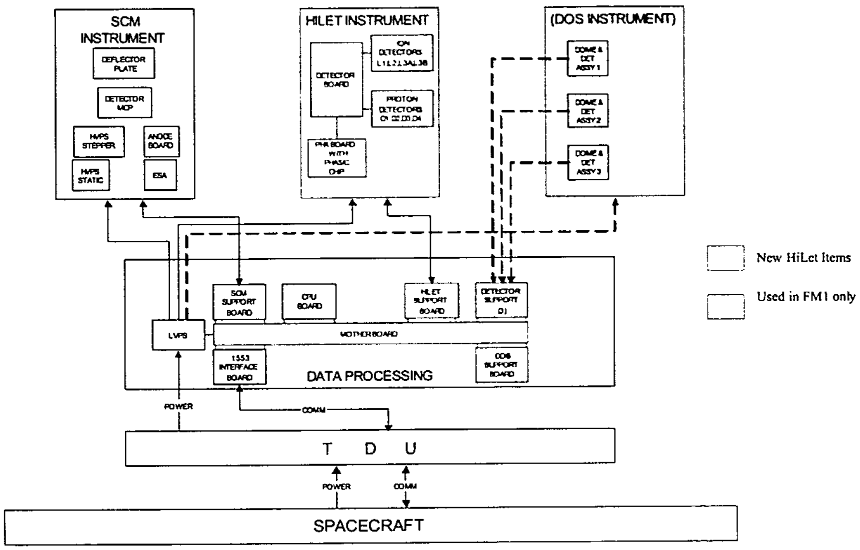


DOS/SCM Flight Model 2 Changes

- Hardware Changes
  - Remove Dosimeters
  - Add HiLET sensors
  - Change motherboard
  - Add CPU I/F board (HiLET Support Board)
- Hardware Unchanged
  - Power supplies (LV & HV)
  - CPU board
  - 1553 board (TDU I/F)
  - SCM plus electronics
  - S/C interface
  - Structure + Ebox



DOS/SCM Block Diagram

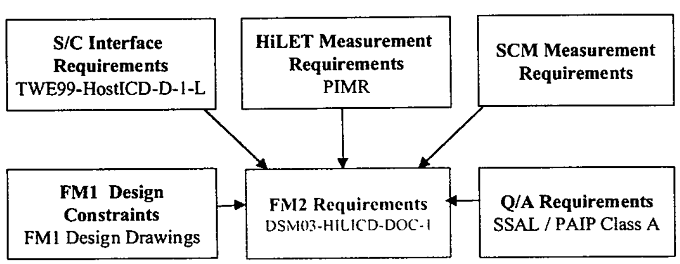


Impact Summary

Category	Technical Impact	Level
Structural Analysis	Created new FEM model; modal & stress analyses performed	Medium
TDU FM2	New telemetry data packet for HiLET; increased operational duty cycle	Medium
Flight Software	Add HiLET telemetry data packets; event selection algorithm; commands	Medium
S/C ICD	Reallocate power & mass to DOS/SCM; no other changes necessary	Medium
EMI	Added noise sources that have potential to affect radiated emissions signature	Low
Thermal Analysis	Updated model and hot/cold predictions	Low
I&T Procedures; Operations	New commands to be added to existing procedures and ground station databases	Low
SCM Performance	No change to measurement specifications, timing, or data bandwidth	Zero
FMEA	No change to S/C electrical interface designs	Zero

Requirements Flowdown

- FM2 requirements for HiLET sensor documented
- Requirements for Host accommodation unchanged (except for new commands to database)
- SCM measurement requirements unchanged
- Quality Assurance requirements per SSAL Product Assurance Implementation Plan Class A



Measurement Requirements (1/2)

- Geometric Factor (1 cm^2sr)
  - Mechanical
  - Detector active area
- Energy Range (3 – 70 MeV/n for iron)
  - Detector thicknesses
  - PHA board preamp gains
- Particle Species ($6 < Z < 26$)
  - Detector thicknesses
  - PHA board coincidence
  - PHA board E-thresholds
  - PHA board layout
  - Detector board layout
  - Thermal control
- Field-of-View (> 45 deg)
  - Mechanical
  - S/C Accommodation
- Mass Resolution (<0.5 amu)
  - Detector resolution
  - Thermal design
  - PHA board electronic noise
  - PHA board layout
  - Detector board layout
- Event Rate (1 kHz PHA Events)
  - PHA board readout FPGA
  - PHA board event memory
  - Support board interface
  - Software / Telemetry

Heavy Ion Telescope

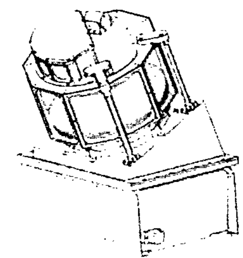
Measurement Requirements (2/2)

- Geometric Factor (10^{-2} - 10^{-3} cm^2sr)
  - Mechanical
  - Detector active area
- Energy Range (6 – 20 MeV)
  - Detector thicknesses
  - PHA board coincidence
  - PHA board gains
- Particle Species (Protons, Electrons > 500 keV)
  - Detector thicknesses
  - PHA board coincidence
  - PHA board E-thresholds
  - PHA board layout
  - Thermal design
- Field-of-View (aligned to Ion)
  - Mechanical
  - S/C Accommodation
- Event Rate (1 kHz in Spectral Bins)
  - PHA board readout FPGA
  - PHA board event memory
  - Support board interface
  - Software / Telemetry
- Event Rate (1 kHz PHA Events)
  - PHA board readout FPGA
  - PHA board event memory
  - Support board interface
  - Software / Telemetry

Proton Telescope

Other Design Constraints

- HiLET pointing constrained by mechanical features
- HiLET board sizes and spacing constrained by envelope and SCM hemispheres
- Limited electrical interface options between HiLET and Electronics Box CPU
- Mass limited by stress margins and existing budget
- Power limited by budget and to a lesser extent by thermal
- Low voltage power supply
- Limited telemetry bandwidth



S/C Interface Requirements

- 44 ICD requirements apply to DOS/SCM
- HiLET designed in scope of the DOS/SCM FM1 interface accommodation
  - Exception: reallocation of mass and power budgets needed to maintain acceptable margin going into build phase
  - No change to envelope, FOV, mounting, or electrical
- Changes to verification products
  - 20 requirements will have new verification procedures
  - 24 verification products from FM1 unaffected

S/C Interface Verification Matrix (1/3)

Physical Properties and Resource Requirements Summary

	Spacecraft ICD Requirement	FM2 Design w/ HiLET	Compliance Status @ CDR	Final Verification Method
Physical Properties / Resources	TWES 3010, 3020 - Failure Isolation	No change	Comply	ANALYSIS - FMEA
	TWES 3080 - Envelope	Increased height	Comply	INSPECTION
	TWES 3100 - Weight NTE 15 lbs	Added weight	Marginal	DEMONSTRATION
	TWES 3110, 3115 - Center-of-Gravity; +/- 0.25 in tol.	Moved CG location	Comply	TEST
	TWES 3120 - provide MOI & POI with 3% uncertainty	Changed MOI / POI	Comply	TEST
	TWES 3130 - Power NTE 13 Watts	Added power	Marginal	TEST
	TWES 3140 - Standby Power NTE 0 Watts	Eliminated DOS power	Negative (same as FM1)	ANALYSIS
	TWES 3142 - Transfer Orbit Power NTE 0 Watts	Eliminated DOS power	Comply	ANALYSIS
	TWES 3360 - Payload ID	No change	Comply	INSPECTION
	TWES 3425 - Venting	Added vent path	Comply	INSPECTION
	TWES 3430, 3440 - Outgassing TML / CVCM	Few new materials	Comply	INSPECTION - Materials List

S/C Interface Verification Matrix (2/3)

Mechanical and Electrical Requirements Summary

Mechanical	TWES 4032 - Surface Flatness	No change	Comply	TEST
Mechanical	TWES 4070 - Connectors	No change	Comply	INSPECTION
Mechanical	TWES 4150 - Stowed stiffness > 70 Hz	New structural model	Comply	ANALYSIS / TEST - Structural Analysis (Modal)
Mechanical	TWES 4195 - Structural Stress: Positive Margin of Safety	New structural model	Comply with notching input spec	ANALYSIS / TEST - Structural Analysis (FEM)
Elect.	TWES 5280 - Direct Telemetry Output Requirements	No change	Comply	ANALYSIS - Failure Modes & Effects Analysis
Elect.	TWES 5400, 5470 Power Transients	No change	Comply	TEST
Structural	TWES 6060 - Acoustic Pressure	Sensitive detector foils	TBD	TEST - Acoustic Test
Structural	TWES 6070 - Static Pressure	New analysis	Comply	ANALYSIS
Structural	TWES 6080 - Dynamic Pressure	New analysis	Comply	ANALYSIS

S/C Interface Verification Matrix (3/3)

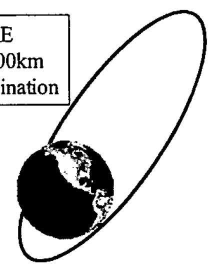
EMI / ESD Requirements Summary

EMI / ESD	TWES 7050, 7060 Inrush Current	No change	Comply	TEST
EMI / ESD	TWES 7070, 7090 Signal Lead Conducted Emissions	No change	Comply	TEST
EMI / ESD	TWES 7110 - DC Magnetic Field Emissions	No change	Comply	TEST
EMI / ESD	TWES 7120 - Radiated E-field Emissions	New noise sources	TBD	TEST
EMI / ESD	TWES 7250, 7260, 7270, 7280 - Grounding / Isolation	No change	Comply	TEST
EMI / ESD	TWES 7285 Bonding of enclosure panels	Same design rules	Comply	TEST
EMI / ESD	TWES 7300 - Bonding of mounting interface	No change	Comply	N/A
EMI / ESD	TWES 7310 - Surface Treatment - gold Iridite	No change	Comply	INSPECTION
EMI / ESD	TWES 7370 - Surface resistivity	Detector foils	Comply	TEST
EMI / ESD	TWES 7380 - Bonding of external conductors	Detector foils	Comply	TEST
EMI / ESD	TWES 7390, 7400 - Thermal blanket bonding	No change	Comply	INSPECTION
EMI / ESD	TWES 7410 - ESD protection	No change	Comply	N/A
EMI / ESD	TWES 7420 - Silver Teflon usage	No change	Comply	INSPECTION
EMI / ESD	TWES 7430 - Construction of external cables	No change	Comply	INSPECTION

Concept of Operations (1/2)

- 100 % operational duty cycle
- Mission life is 10 years
  - No life limiting materials
  - Designed for 10-year total dose
- Normal mode
  - 3 kbps data rate
  - No routine commanding
- Maintenance mode
  - Infrequent
  - Existing mode on DOS/SCM for uploads
  - HiLET configuration changes (PHASIC settings)
- In-flight calibration ops
  - Bi-weekly (to be timed with SCM)
  - Supports detector leakage current and test pulser functions

Apogee 7RE
Perigee 1000km
63 deg inclination



Concept of Operations (2/2)

- New ground commands needed to support HiLET
  - HiLET Detector Bias On/Off
  - HiLET Pulser On/Off
  - HiLET Pulser Level (8-bit variable)
  - HiLET Calibration On/Off
- Memory Uploads
  - Same upload command structure as FM1
  - HiLET Proton Matrix Lookup Table (64 kbytes)
  - HiLET PHASIC Configuration Data (~320 bytes)

Power Margin

- Total FM2 TWINS/ES power complies with ICD with added uncertainty margins (10% CDR, 3% un-built, 0% delivered)
- Small negative margin on DOS/SCM unit power for FM2)

TWINS/ES Unit	ICD Budget (Watts)	FM1 measured (Watts)	FM2 at CDR (Watts)	Anticipated Uncertainty Margin	FM2 final (Watts)
DOS/SCM	**13**	**13.2**	**13.3**	**10%**	**14.6**
TWINS	27	26.5	26.5	3%	27.3
TDU	4	2.60	2.80	0%	2.80
Heaters	30	27	27	3%	27.8
TOTAL	**74**	**69.3**	**69.6**		**72.5**

On-Orbit Power Profile

S/C Operational Mode

FM2 TWINS/ES Units	Unit Budgets	Full Ops	Reduced Ops (RadBelts)	Standby 1	Standby 2	Transfer
TWINS	27	26.5	24.2	13.4	0.0	0.0
DOS/SCM	13	13.3	8.4	8.4	8.4	0.0
DPU/Ebox		6.1	6.1	6.1	6.1	0.0
HiLET		2.3	2.3	2.3	2.3	0.0
SCM HV		4.9	0.0	0.0	0.0	0.0
TDU	4	2.8	2.8	2.8	0.0	0.0
Heaters	30	27.0	29.3	34.9	34.9	8.6
Total Power		69.6	64.7	59.5	43.3	8.6
S/C ICD NTE Rqmt.		74.0	n/a	n/a	35.0	11.0
Margin		6.4%	n/a	n/a	-19.2%	27.9%

- No changes to on-orbit operational power profile from FM1
- Negative margin on FM2 Standby 2 also problematic on FM1 and is being accommodated by S/C with additional 8.3 W

Mass Margin

- Total FM2 TWINS/ES mass complies with ICD with added uncertainty margins (10% CDR, 3% un-built, 0% delivered)
- No existing margin on DOS/SCM unit mass budget for FM2

TWINS/ES Unit	ICD Budget (lbs)	FM1 measured (lbs)	FM2 at CDR (lbs)	Anticipated Uncertainty Margin	FM2 final (lbs)
DOS/SCM	**15**	**13.7**	**14.9**	**10%**	**16.4**
TWINS	47	42.1	42.1	3%	43.4
TDU	5	4.32	4.63	0%	4.63
TOTAL	**65**	**60.1**	**61.6**		**64.4**

Documentation (1/4)

- Configuration Control
  - All drawings (including schematic diagrams) that are generated, relative to fabrication or assembly of deliverable product, are controlled
  - Controlled drawings are maintained by the Quality Assurance Manager in accordance with project requirements
    - Controlled documents require an Engineering Change Order (ECO) for red-line modifications
    - Document revisions are controlled by the Aerospace document *Product Assurance Project Configuration Control*
  - Formal Configuration Control of fabrication/assembly drawings will begin no earlier than the completion of CDR

Documentation (2/4)

Unit Level Documents

PART NUMBER	DESCRIPTION
DSM03-DSMASSY-TR	DOS/SCM Unit Assy Traveler
DSM03-COMPTEST-TR	DOS/SCM Functional Test Procedure
DSM03-TESTSETUP-TR	DOS/SCM Test Setup Procedure
DSM03-HILICD-DOC	HiLET Interface Control Document

Mechanical Drawings

PART NUMBER	DESCRIPTION
DSM03-HBASE-MD-1	HiLET Base
DSM03-HHSNG-MD-1	HiLET Detector Housing
DSM03-HTCOVER-MD-1	HiLET Top Cover
DSM03-HPHACVR-MD-1	HiLET PHA Cover
DSM03-L2L3MNT-MD-1	L2 L3 Detector Mount
DSM03-L2L3SPNG-MD-1	L2 L3 Retention Spring
DSM03-L2L3STFF-MD-1	L2 L3 Stiffener
DSM03-L2L3SPCR-MD-1	L2 L3 Spacer
DSM03-L1BASE-MD-1	L1 Detector Base
DSM03-L1CAP-MD-1	L1 Detector Cap
DSM03-L1SCRN-MD-1	L1 Detector Screen Mount
DSM03-BRDSPCR-MD-1	Board Spacer
DSM03-PHASHLD1-MD-1	Phasic Shield 1
DSM03-PHASHLD2-MD-1	Phasic Shield 2
DSM03-HWG-MD-1	HiLET Wire Guide
DSM03-HWGCVR-MD-1	HiLET Wire Guide Cover
DSM03-HBRDRET-MD-1	Board Retainer
DSM03-SWG-MD-1	SCM Wire Guide
DSM03-SWGCVR-MD-1	SCM Wire Guide Cover
DSM03-PTBASE-MD-1	Proton Telescope Base
DSM03-PTSNT-MD-1	Proton Telescope Snout
DSM03-PTCVR-MD-1	Proton Telescope Cover
DSM03-PTSPCR-MD-1	Proton Telescope Spacer
DSM03-PTCLMTR-MD-1	Proton Telescope Collimator
DSM03-PTCSPCR-MD-1	Proton Telescope Collimator Spacer

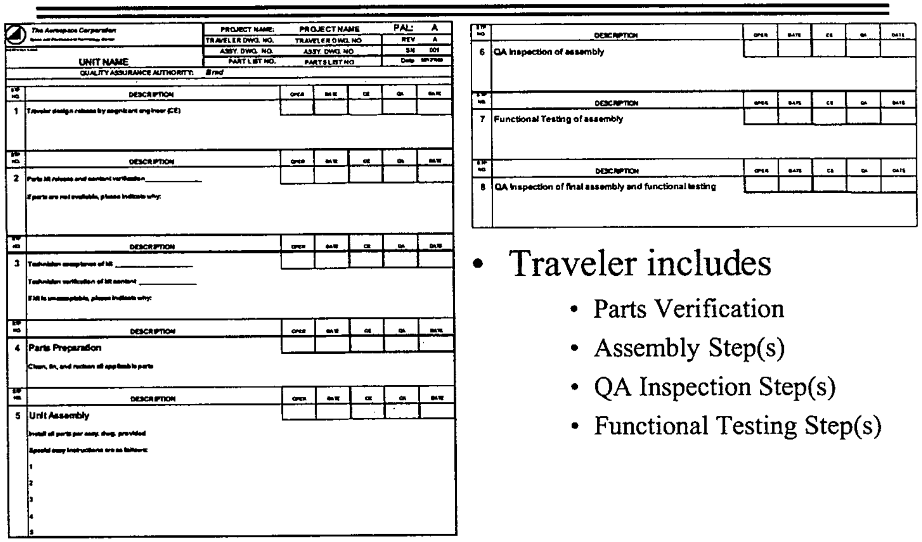
Electronics Drawings

PART NUMBER	DESCRIPTION
DSM03-HILPHA-ES	HiLET PHA Board Schematic
DSM03-HILPHA-PC	HiLET PHA Board PCB Layout
DSM03-HILPHA-PL	HiLET PHA Board Parts List
DSM03-HILPHA-TR	HiLET PHA Board Assy Traveler
DSM03-HILDET-ES	HiLET Detector Board Schematic
DSM03-HILDET-PC	HiLET Detector Board PCB Layout
DSM03-HILDET-PL	HiLET Detector Board Parts List
DSM03-HILDET-TR	HiLET Detector Board Assy Traveler
DSM03-HILSUP-ES	HiLET Support Board Schematic
DSM03-HILSUP-PC	HiLET Support Board PCB Layout
DSM03-HILSUP-PL	HiLET Support Board Parts List
DSM03-HILSUP-TR	HiLET Support Board Assy Traveler
DSM03-MTHRBD-ES	DOS/SCM Mother Board Schematic
DSM03-MTHRBD-PC	DOS/SCM Mother Board PCB Layout
DSM03-MTHRBD-PL	DOS/SCM Mother Board Parts List
DSM03-MTHRBD-TR	DOS/SCM Mother Board Assy Traveler
DSM03-HILCAB-ES	HiLET Interface Cable Schematic
DSM03-HILCAB-PL	HiLET Interface Cable Parts List
DSM03-HILCAB-TR	HiLET Interface Cable Assy Traveler

Documentation (3/4)

- The Assembly Traveler remains with a product during its entire production life
  - The Assembly Traveler is used to control the flow of hardware through the manufacturing process
  - Travelers are used primarily for printed circuit board assemblies, harness assemblies, and unit assembly
  - QA steps ensure that only conforming product is released and used during fabrication
  - This is a SSAL class A project per PAIP; highest level of quality assurance

Documentation (4/4)



- Traveler includes
  - Parts Verification
  - Assembly Step(s)
  - QA Inspection Step(s)
  - Functional Testing Step(s)

Contamination

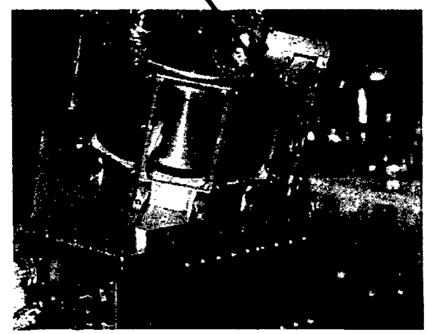
- All new and existing materials conform to ASTM-E-595 test results
  - 1 % Total Mass Loss
  - 0.1 % Collected Volatile Condensable Material
- Venting direction is defined and in accordance with spacecraft requirements
- Instrument is sensitive to vapor and particulate contamination
  - Contamination control plan currently in place for FM1 is sufficient for FM2 (HiLET)
  - No active purge requirements

Safety and Handling

- Delicate surfaces not to be touched
  - Delicate HiLET detector assembly has thin foils which can be damaged from poor handling
  - SCM aperture has very delicate EMI screens
  - ITO thermal control surfaces will degrade thermally and electrically if touched
- Total instrument lifting weight is ~ 16 lbs
  - Includes lift handles and protective covers
- High voltage
  - 5000 volts on SCM aperture as in FM1
  - HiLET voltage < 300 volts and not externally accessible
- No pyrotechnic devices or deployable systems

EMI Radiated Emissions

- Undesirable RF power at highest impedance level requires careful attention (32MHz oscillator)
- I/F conduit surface impedance and shield termination is key and should require no changes

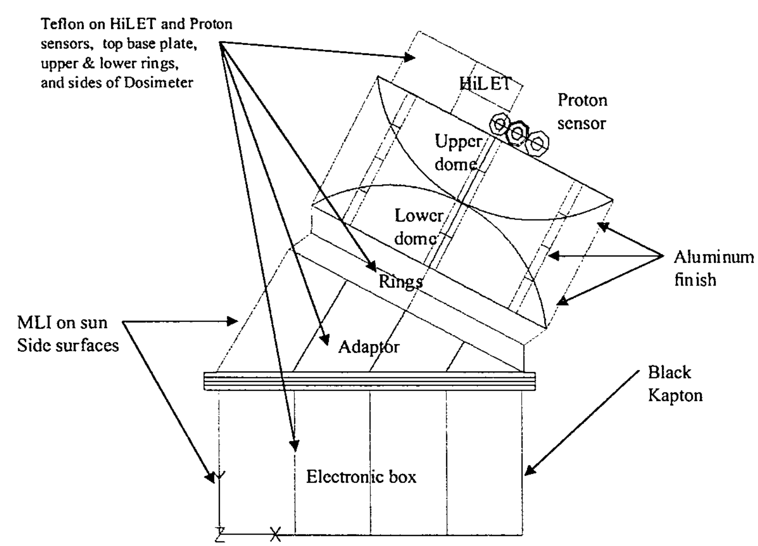


- EMI design of HiLET
  - Minimize digital noise in upper PCBs
  - Slow differential serial interface to electronics box
  - 100% shielded design
  - Maintain tight seams (~ 1-inch screw spacing)

Thermal Design

- Aerospace Thermal Department
  - Design and analysis by M. Chang and T. Dickey
- No changes from basic FM1 thermal design
  - Relies on absorption and emissivity of thermal surfaces
  - No heaters
  - No active cooling
- Sensors and boards are hard mounted
- Surface finishes
  - Black Kapton on anti-sun side of electronic box
  - MLI on sun-sides of electronic box and triangle adaptor
  - All other surfaces covered with ITO silvered Teflon tape

Thermal Model (1/4)



Thermal Model (2/4)

- 30 nodes
- Hot case assumptions:
  - Beta angle = 0°, Winter, solar flux is 444 Btu/hr/ft²
  - End of life physical properties
  - Spacecraft is at 100°F
- Cold case assumptions:
  - Beta angle = 40°, Summer, solar flux is 415 Btu/hr/ft²
  - Beginning of life physical properties
  - Spacecraft is at 60°F
- Transfer orbit assumptions:
  - All units powered off
  - Beginning of life physical properties
  - Spacecraft is at 60°F

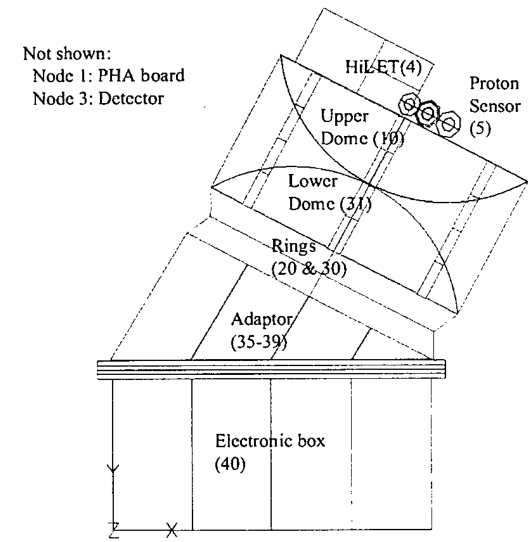
Surface Properties

Surface finish	_ - Emissivity		_ - Solar absorptivity	
	Begin-of-life	End-of-life	Begin-of-life	End-of-life
ITO Silver Teflon	0.8	0.8	0.13	0.25
MLI	0.049	0.049	0.0308	0.0308
Black Kapton	0.91	0.91	0.98	0.94
Aluminum	0.03	0.03	0.15	0.24

Temperature Limits

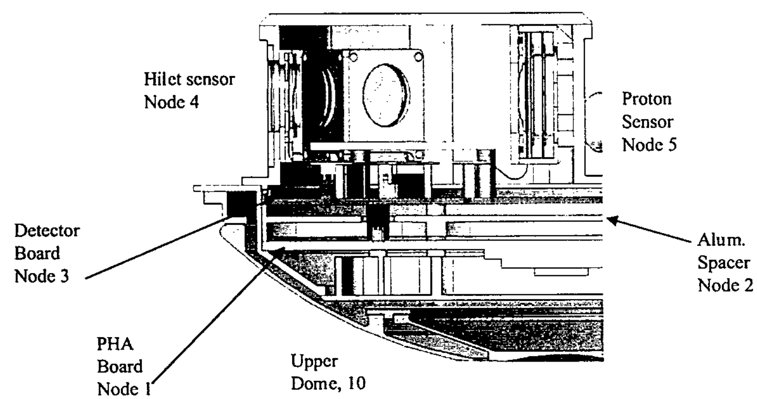
Mode	Minimum Temperature (°C)		Maximum Temperature (°C)	
	Circuit boards	Sensors (SCM & HiLET)	Circuit boards	Sensors (SCM & HiLET)
Operate	-30	-40	35	35
Non-operating (Survive)	-30	-40	60	60

Thermal Model (3/4)



Thermal Model (4/4)

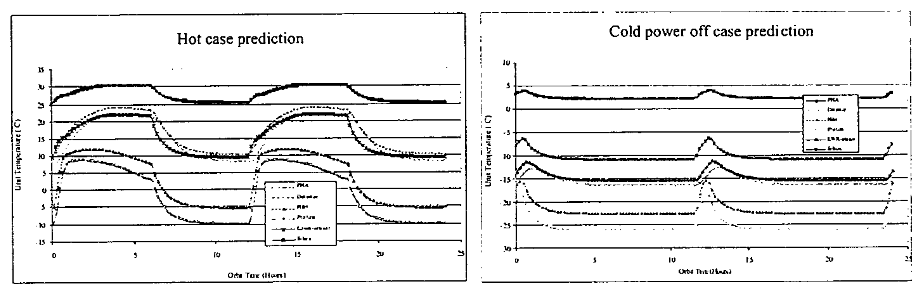
HiLET Thermal Model Detail



Thermal Predictions – Normal Orbit

Hot/cold predictions demonstrate good margin on limits

Unit	Hot case max temperatures (°C)			Cold power off case (°C)		
	Power (W)	Limits	Predict	Power (W)	Limits	Predict
Hilet sensor	0.0	35	12.1	0.0	-40	-22.3
Proton sensor	0.0	35	8.9	0.0	-40	-26.1
Detector board	0.0	35	22.2	0.0	-30	-16.2
PHA board	1.3	35	24.2	0.0	-30	-15.2
SCM	1.47	35	22.0	0.0	-40	-10.7
Ebox boards	12.41	35	30.4	0.0	-30	2.2



Note: *Lower Sensor = SCM*

Thermal Predictions – Transfer Orbit

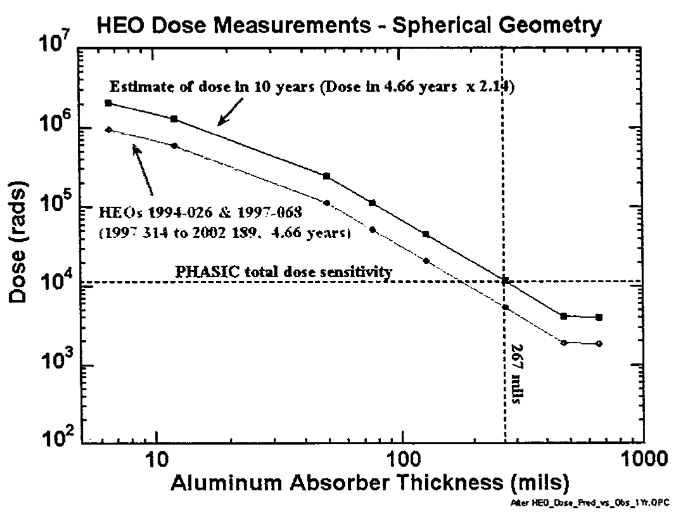
Transfer orbit temperatures are safely within cold limits

Unit	Power (W)	Limits (°C)	Transfer orbit Predict (°C)
Hilet sensor	0.0	-40	-20.3
Proton sensor	0.0	-40	-23.9
Detector board	0.0	-30	-14.7
PHA board	0.0	-30	-13.5
SCM	0.0	-40	-9.5
Ebox boards	0.0	-30	2.7

Radiation Design

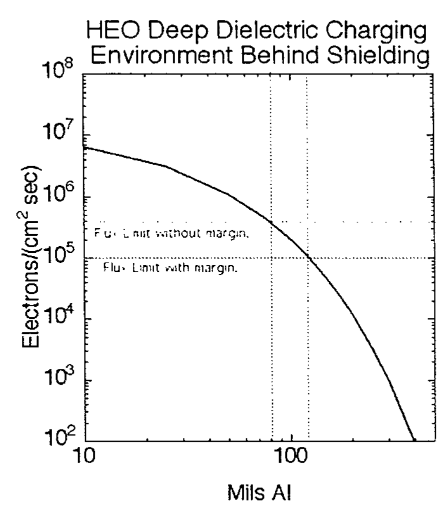
- Total dose design based on HEO measurements to date, extrapolated to 10-year mission
  - Procured microcircuits to 100 Krad hardness
  - Implemented spot shields for PHASIC protection
- Single event effects mitigated by component test data
  - No latchup susceptibilities including PHASIC chip
  - SEU test data indicates < 1 error over mission
- Deep-dielectric and surface charging mitigated by shielding, materials selection, and grounding
  - Applied Frederickson safe flux level guidelines
  - Incorporated thicker shielding around backside of detectors to further reduce electron flux
  - No internal or external floating conductors

Total Dose Environment



HEO charging environment

- **Internal charging specification (*Fennell et al. IEEE Trans. Plasma Sci. 28, 6, 2000*)**
- **Mitigated**
  - **80-120 mils Al structure**
  - **Extra shielding for dielectrics inside of heavy-ion sensor that are directly in view of front L1 detectors**



Summary

- HiLET sensor can be accommodated with minor technical impact on FM1 system design
  - No changes to spacecraft mechanical and electrical interfaces
  - No impact on SCM performance
- No failure modes have been added that would affect Host mission
- Revision of DOS/SCM operating procedures will be necessary to support HiLET
- Mass and power budgets under review

Mechanical System Design

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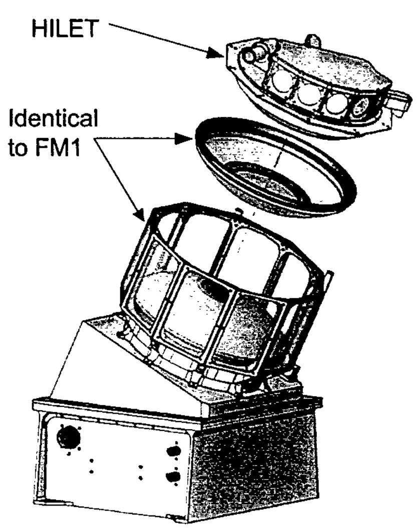
Mechanical Design Requirements

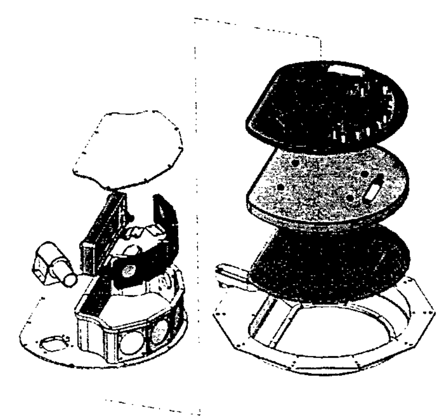
- Comply with S/C ICD
  - Mass Properties
  - Envelope
  - Venting
  - EMI
  - Structural
- No changes to SCM or E-box mechanical designs
- Provide stand-alone capability (HiLET & SCM)
- Meet HiLET FOV and geometric factor requirements
- Mitigate radiation and charging hazards

Mechanical Overview (1/2)



- HILET mounts onto structure that is identical to FM1
- S/C mounting interface is unchanged
- SCM packaging and internal harness are identical to FM1

Mechanical Overview (2/2)



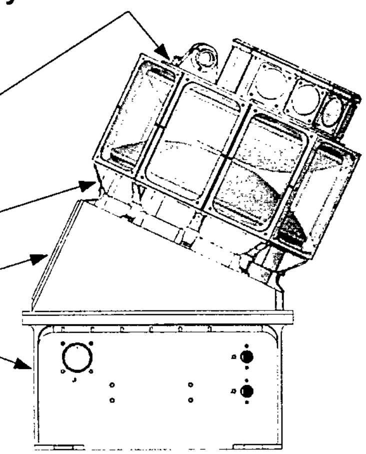
- Heavy ion telescope
- Proton telescope
- Detector board
- PHA board
- 0.080" wall thickness to mitigate internal charging
- All cables are internally routed to reduce EMI

Mass Properties (1/2)

- Total weight is 14.9 pounds
- All FM2 parts except HiLET already machined

Component	Weight (lbs)	% of FM2
HiLET	2.84	19.0%
Misc*	.39	2.7%
SCM Assy	3.90	26.1%
Wedge Assy	1.18	7.9%
E-box	6.59	44.3%
Total	14.90	100%

*Misc is conduit/cable/connector allocation



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Mass Properties (2/2)

- FM2 CG is within 1" tolerance of CG in ICD

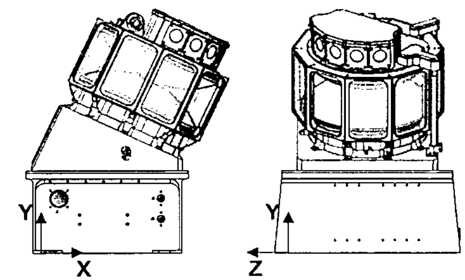
Axis	FM2	ICD	Change
X	4.47	4.44	0.03
Y	5.59	5.33	0.26
Z	-4.76	-5.74	0.98

Moments of Inertia (lb-in^2)

I_{xx}=293 I_{xy}=52 I_{xz}=-3

I_{yx}=52 I_{yy}=176 I_{yz}=1

I_{zx}=-3 I_{zy}=1 I_{zz}=306



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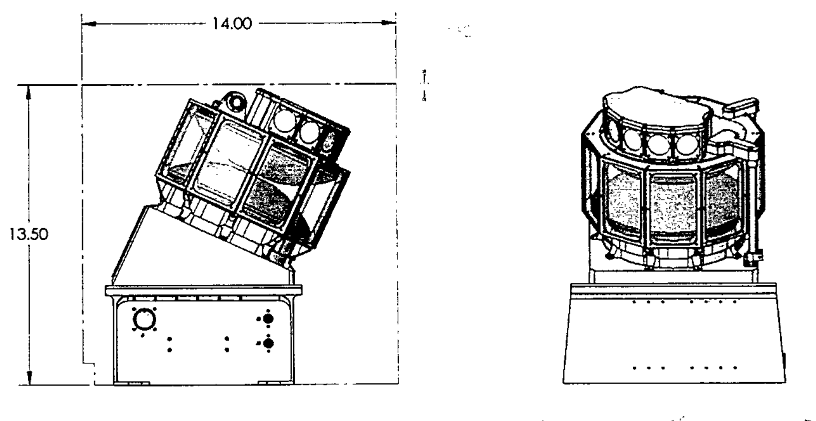
Envelope

- DOS/SCM FM2 fits within envelope



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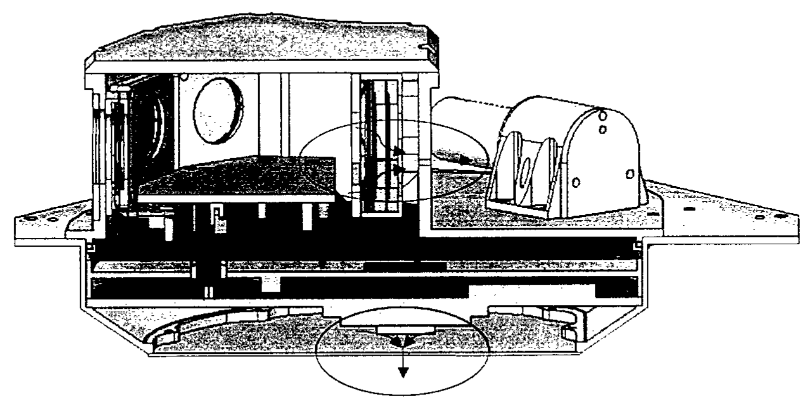
Venting (1/2)

- .063 diameter holes will adequately vent enclosure



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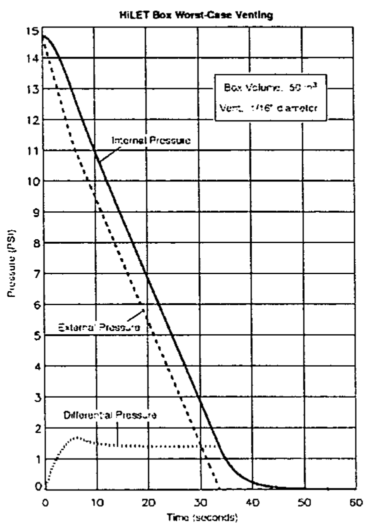
Venting (2/2)

- 1.7 psi maximum pressure build up across enclosure walls
- Characteristic venting time of 3.5 seconds much less than time constant for external pressure decay of 19.5 seconds



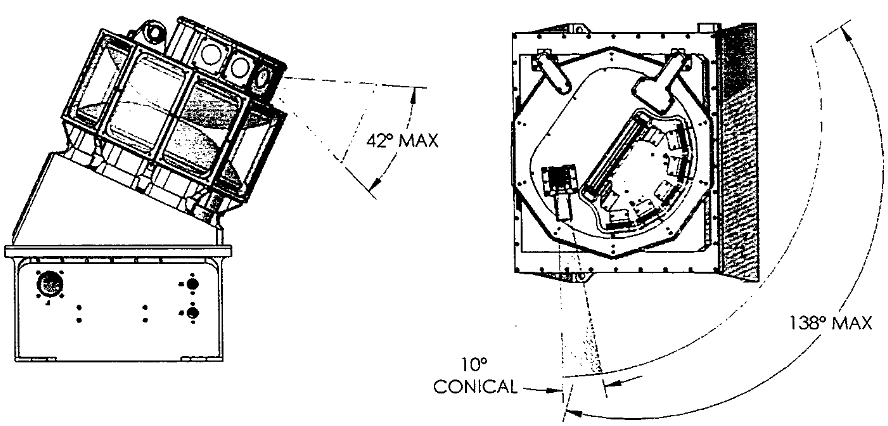
Material List

•All materials comply with <1.0% TML and <.10% CVCM outgassing spec

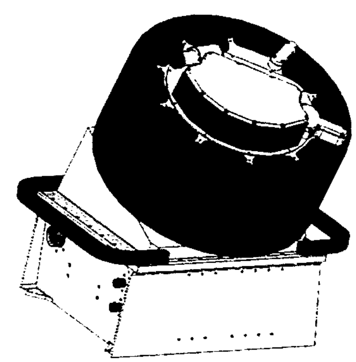
Material	TML	CVCM	Material	TML	CVCM
Aluminum 6061-T6	<0.1	<0.05	Flux RMA	0.34	<.05
Gold Iridite Finish	<0.1	<0.05	Urethane	0.6	<.05
Gold Plating	<0.1	<0.05	Polyimide HTE/Glass	0.82	<.05
18-8 Stainless Steel	<0.1	<0.05	Solid, Insulated Wire	0.22	<.05
Molybdenum Disulphide	<0.1	<0.05	Silicone Adhesive	0.2	0.03
Phosphor Bronze	<0.1	<0.05	Delrin	0.8	0.09
Tantalum	<0.1	<0.05	Lacing Tape	0.58	0.09
Silicon	<0.1	<0.05	Viton	0.21	0.02
Sintered Ferrite	<0.1	<0.05	FR4 PCB	0.21	0.01
Teflon	<0.1	<0.05	Black Liquid Crystal Polymer	0.41	0.11
Solder	<0.1	<0.05	3M Scotch-Weld 2216 B/A	0.77	0.04
Tantalum	<0.1	<0.05			

Fields of View

- Overlap between proton and heavy ion telescope



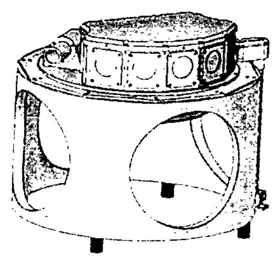
Handling

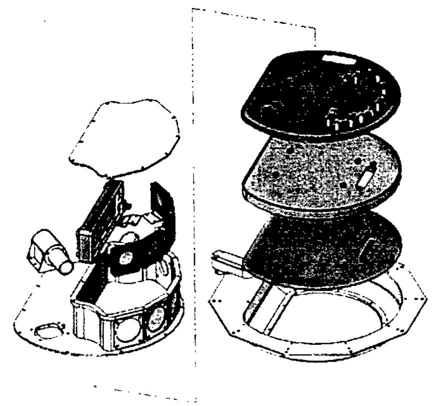


- Removable handles with captive screws
- SCM cover
- Ion telescope cover
- Proton telescope cover
- 15.7 lbs lift weight

HiLET Features (1/2)

- Stand-alone capability
- Simple assembly





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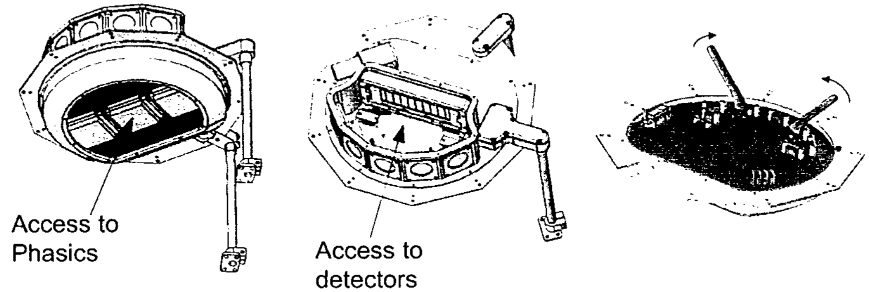
HiLET Features (2/2)

- Access to circuit boards and detectors
- Board extraction using levers



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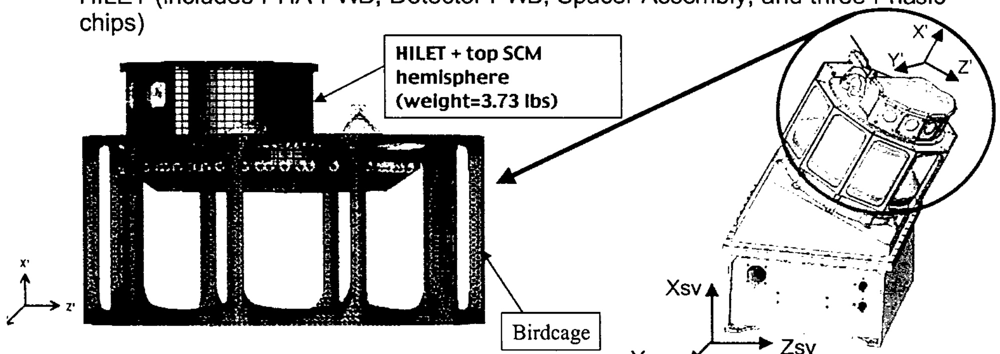
FM2 DOS/SCM HILET Structural Analysis

15 January 2004

M. Papadopoulos/ Structures Dept
E. Pierre-Louis/ Mechanical Systems Dept
M. B. Van Dyke/ Environment & Ordnance Dept

DOS-SCM Structural Analysis Methodology

- Analysis performed to assess structural integrity due to changes from FM1 to FM2 flight units
- 3D finite-element model created for DOS-SCM FM2 assembly from base of Birdcage and up
  - 47,641 solid, shell, and beam elements for integrated model of Birdcage and HILET (includes PHA PWB, Detector PWB, Spacer Assembly, and three Phasic chips)



Birdcage with HILET model (unit weight= 4.42 lbs)

DOS-SCM Structural Analysis Methodology

- Modal analysis conducted with MSC/NASTRAN Code to predict fundamental modes of critical components
- Static analysis with acceleration loading used to determine peak stresses
  - Single degree of freedom root mean square response, G_{rms}, employed to estimate peak Gs

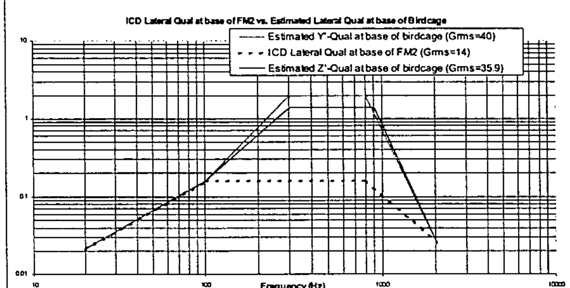
$$G_{peak} = 3 * G_{rms} = 3 * \sqrt{\frac{1}{2} * \pi * PSD * f * Q}$$

  / Dynamic amplification (Q) of 20 assumed (based on FM1 random vibration test data from Birdcage)

- Qualification random vibration levels (+6 dB above Acceptance) used for analysis
- Vibration input to base of Birdcage used for analysis
  - Derived from FM1 random vibration test data

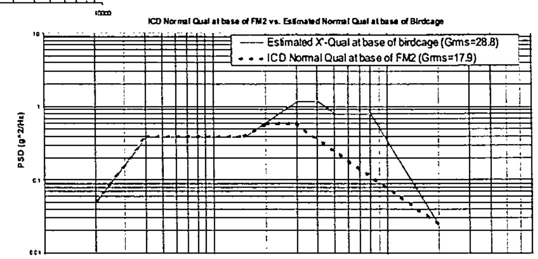
DOS-SCM Structural Analysis Methodology

- Derived Qualification vibration input spectrum based on FM1 test data



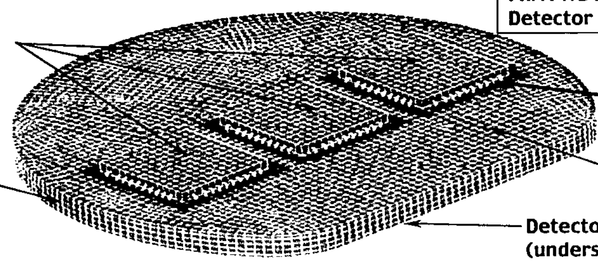
Y'–, Z'– Lateral Axes

X'– Normal Axis



DOS-SCM Structural Analysis Methodology

- Stress margins of safety calculated using maximum of qualification-level random vibration or quasi-static design limit loads
- Detailed model of PWBs and Spacer (located within HILET structure) used for fatigue assessment of PHA PWB Phasic Chips



  - Manson-Coffin fatigue equation used to relate predicted strain range of Kovar leads to cycles to failure
  - Miner's rule used to estimate Cumulative Damage Index (CDI) under qualification vibration environment
    - / Allowable CDI of 1.0 with scatter factor of 4

DOS-SCM Structural Analysis Results

- Analysis of original design indicated that PHA PWB would experience large deformations
- To reduce stresses on PHA PWB Phasic leads, sensitivity studies performed and following design modifications were incorporated to increase stiffness:
  - Number of attachment from PWBs to spacer increased from 2 to 6
  - Thickened spacer and enhanced spacer rib geometry
  - Increased PHA PWB thickness
- Even with modifications, analysis still predicted **negative** margins of safety for PHA PWB, Birdcage, and HILET Top Plate
- To prevent structural damage, notching at critical modes will be used
  - Notch levels derived to show zero yield and/or fatigue margin at qualification-level random vibration

DOS-SCM Structural Analysis Results

- Analysis indicates DOS-SCM FM2 assembly of Birdcage and HILET can safel) withstand qualification random vibration with proposed notches

Component	Material	Direction	Freq (Hz)	Notched Qual G	Notched Peak Stress, psi @ Qual vib	Allowable, psi	[redacted]
Birdcage	Aluminum 6061-T6	Z	130	59	35,000	35,000 yld	
		X	>2000	81	7,468		
		Y'	130	62	33,778		
HILET Top Plate	Aluminum 6061-T6	Z	130	57	30,189	35,000 yld	
		X	681	399	25,715		
		Y'	130	61	26,248		
PHA Phasic Leads	Kovar	X	522	140	44,564	50,000 yld	
PHA PWB	Polyimide	X	522	156	3,906	28,000 yld	
Detector PWB	Polyimide	X	522	191	4,208	28,000 yld	
PHA Phasic Leads	Kovar	X	522	140	44,564	-	

*Yield Margin=Allowable stress/(FS*Notched Peak Stress)-1
**Fatigue Margin=(1.0/CDI)-1 (includes scatter factor of 4)

Justification for Notched Vibration Test

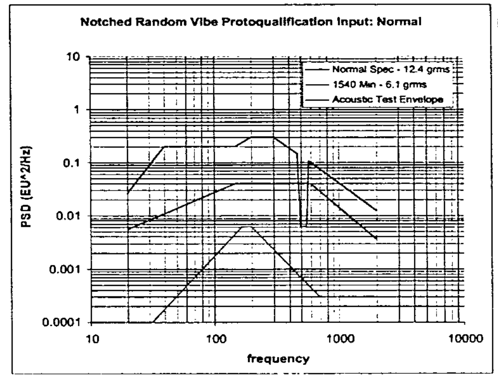
- Structural analysis indicates notching needed to demonstrate positive margin
- Notching allowed by MIL-STD 1540C to prevent over-testing of sensitive components
  - Artificial modal amplification is well-known effect of subjecting hardware to fixed-base vibration
  - Test article sees shaker table as a virtually infinite impedance (results in large resonant responses)
  - Realistic attach point impedances are much less due to the component load imparted on the support structure
- Proposed notch levels are well above expected SV system acoustic test response levels at the instrument base (measured for FM1)

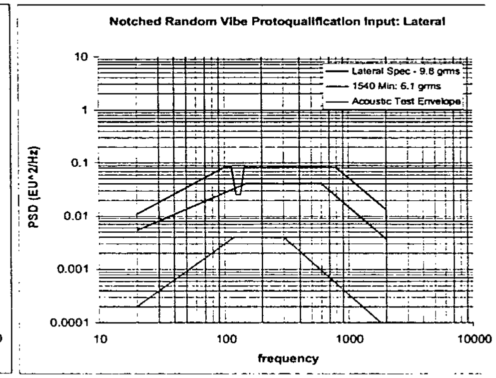
Peak G Response Limits

Axis / freq.	PHA Board Limit G peak	Birdcage Limit G peak	PQ Input Notch Depth (predicted)	PQ Input Notch Level g^2/Hz (predicted)	PQ Acoustic Test FM1 Response Envelope g^2/Hz
Z' / 130 Hz	-	42	5 dB	0.025	0.004
Y' / 130 Hz	-	45	4.5 dB	0.028	0.001
X' / 522 Hz	111	-	13 dB	0.006	0.0006

- 130 Hz is the predicted lateral Birdcage mode
- 522 Hz is the predicted PHA PWB fundamental bending mode
- Predicted input notch levels ≥ 8 dB above the measured proto-qualification (PQ) SV system acoustic test response at the FM1 DOS/SCM base

Predicted Input Notching





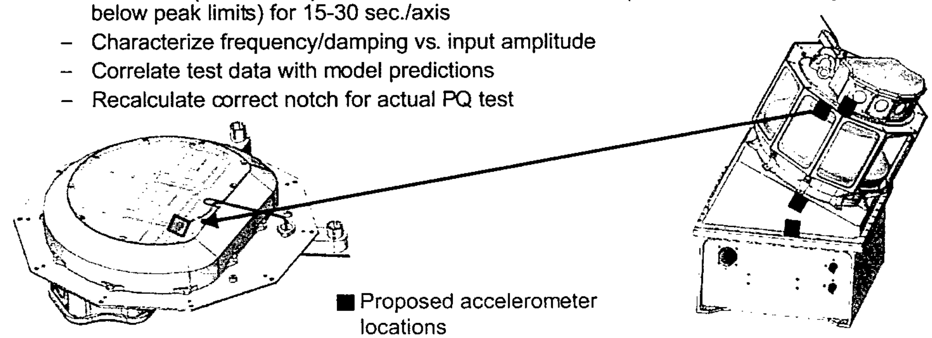
- **Notched test inputs envelope the expected proto-qualification system test/flight environment**
  - Notch levels are at least 8 dB above the levels measured at FM1 unit during system acoustic test
- **Notch depth falls below MIL-STD 1540C minimum workmanship screen guideline**
  - Lateral axis estimated notch is 2 dB below minimum screen level
  - Normal axis estimated notch level is 9 dB below minimum screen level

Additional Vibration Screen Test

- **Normal Axis**
  - Before PQ test, additional test will be performed on DOS/SCM base (Birdcage removed) at MIL-STD-1540C minimum workmanship levels for 1 minute
- **Lateral Axes:**
  - If notch determined in characterization test is no greater than predicted: no additional action is necessary
    - Notch depth of 2 - 3 dB below minimum screen does not appreciably lessen the effectiveness of the screen
  - If notch determined in characterization test exceeds prediction, additional workmanship test will be considered

Proposed Characterization Test

- **Characterization test needed due to inability to monitor PHA PWB notched response during PQ test on flight hardware**
- **Analysis indicates PHA PWB response critical to show positive fatigue margin**
- **<u>Entire flight unit</u> will be used for low-level random vibration test**
  - Use substitute cover plate with accelerometer cable access hole
  - PQ-18 dB (un-notched), PQ-12 dB, PQ-9 dB, PQ-6 dB (notched as necessary to 3 dB below peak limits) for 15-30 sec./axis
  - Characterize frequency/damping vs. input amplitude
  - Correlate test data with model predictions
  - Recalculate correct notch for actual PQ test



HiLET Detectors

Joe Mazur
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HiLET Detectors - Heavy Ion Sensor

- HiLET heavy-ion sensor uses custom silicon solid-state detectors
  - designed for NASA/STEREO mission
  - L1 (20 micron); L2 (50 micron); L3 (1000 micron)
  - Procured by Aerospace from Micron Semiconductor Ltd
  - Same detector specifications as STEREO
  - PO issued 8/2003
- Detector mounts procured by Aerospace (L1 & L2 - Pioneer Circuits; L3 - Rigiflex Technology Inc.)
  - STEREO mount design & specifications (courtesy of NASA/GSFC T. von Rosenvinge)
  - All mounts have been delivered to Aerospace
  - Ready for shipment to Micron after Aerospace Q/A

Heavy Ion Sensor Detectors 1/3

- **L1 design specification:**
  - **Thickness: 20 ± 2 microns**
  - **Thickness uniformity: ±1 micron**
  - **Active area: 2 cm^2**
  - **Leakage current at 2 x full depletion: 10 nA typical 50 nA maximum**
  - **Full depletion: 3 V typical 10 V max**
  - **Operating voltage: FD to 2FD (20 V max)**
- **Number required for flight: 5**
- **Number of spares: 6**

Heavy Ion Sensor Detectors 2/3

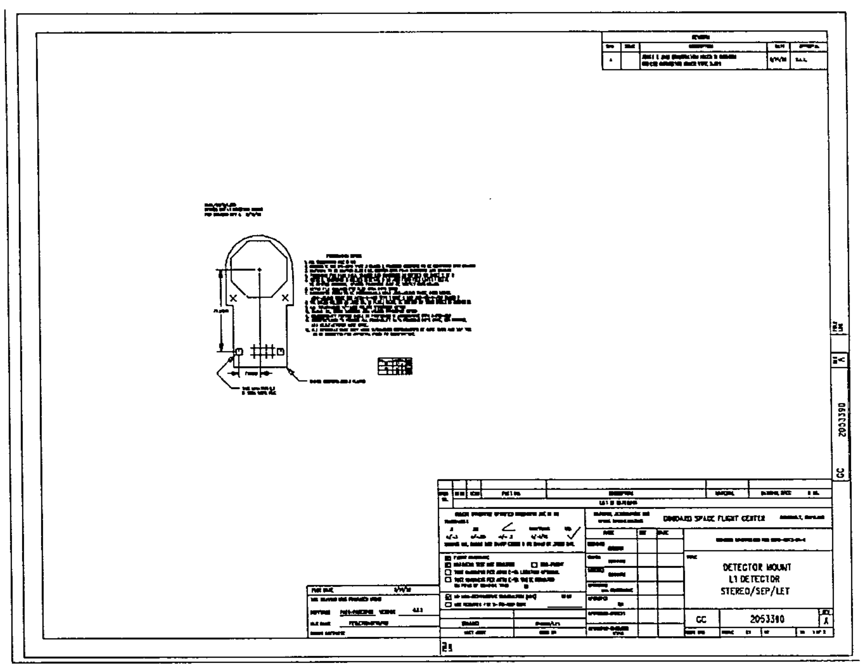
- **L2 design specification:**
  - **Thickness: 50 ± 5 microns**
  - **Active area: 6.4 x 1.6 cm (10 elements)**
  - **Leakage current at 2 x full depletion: 100 nA typical 500 nA maximum**
  - **Full depletion: 10 V typical**
  - **Operating voltage: FD to 2FD (50 V max)**
  - **Alpha resolution 100 keV FWHM**
- **Number required for flight: 1**
- **Number of spares: 2**

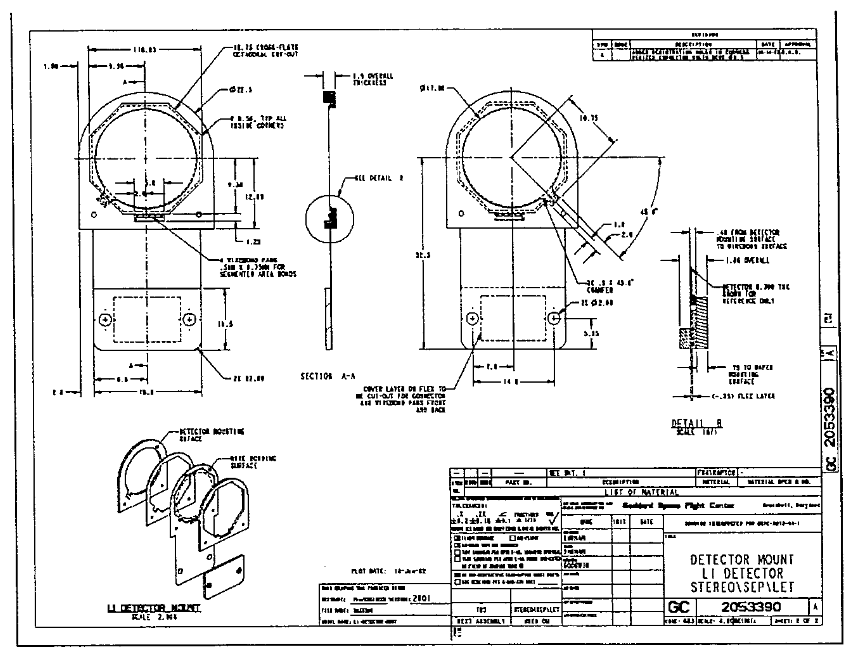
Heavy Ion Sensor Detectors 3/3

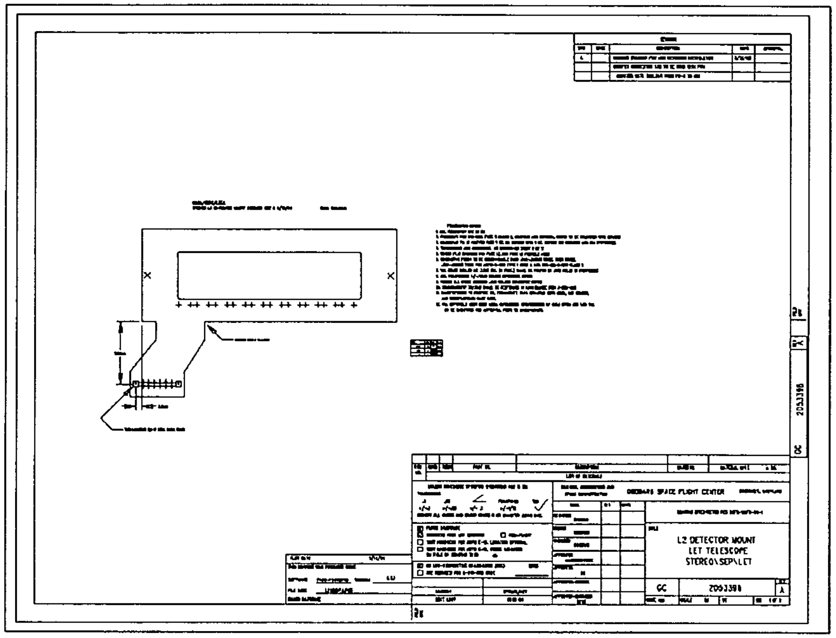
- L3 design specification:
  - Thickness: 1000 ± 50 microns
  - Active area: 7.8 x 2.0 cm (3 elements)
  - Leakage current at full depletion + 30 V: 500 nA typical 2000 nA maximum
  - Maximum operating voltage: 200 V
  - Alpha resolution 100 keV FWHM
- Number required for flight: 2
- Number of spares: 3

Detector Mounts - Heavy Ion Sensor

- Following drawings are from S. Shuman & T. von Rosenvinge, NASA/GSFC
- FM2 project uses same specifications and mount vendors







06-9 DETECTORS

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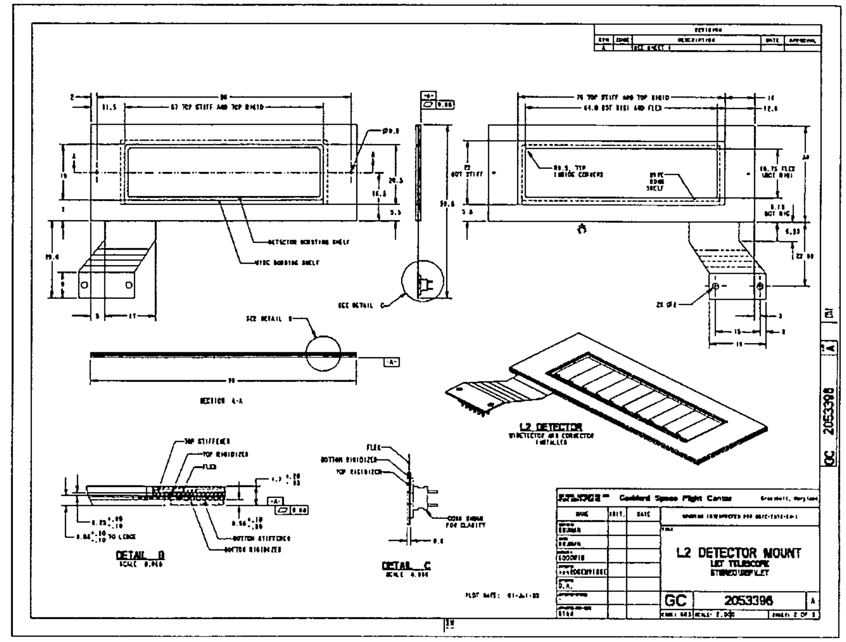

06-10 DETECTORS

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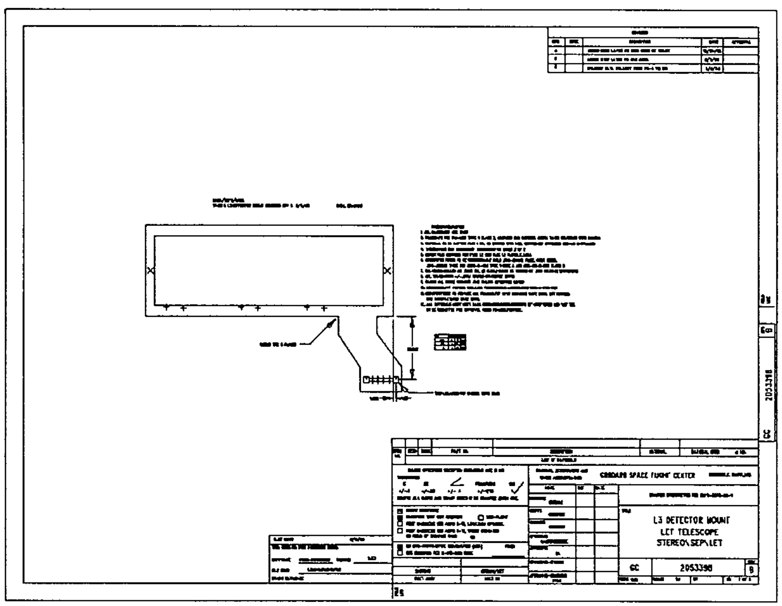

06-11 DETECTORS

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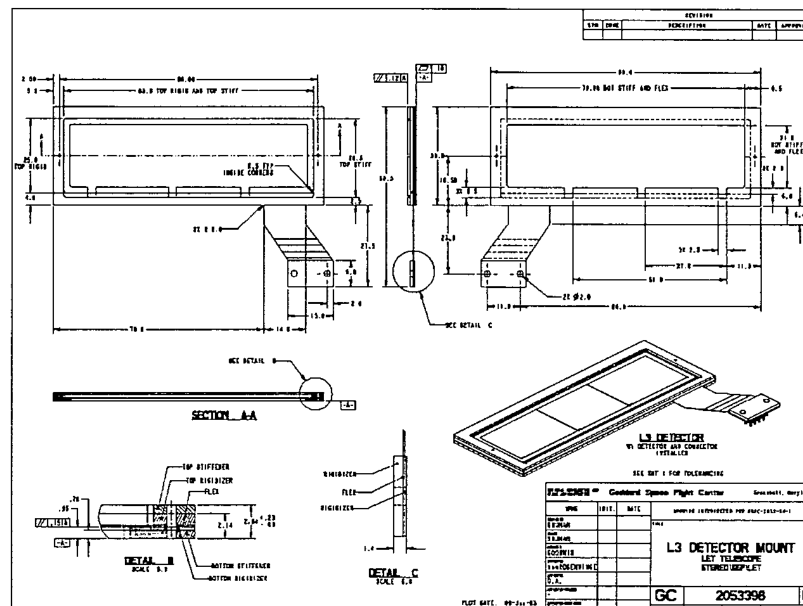

06-12 DETECTORS

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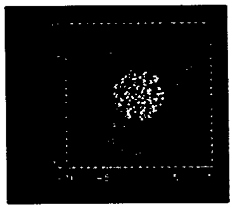
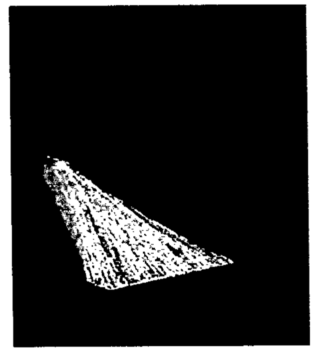
Simulation of Particle Trajectories



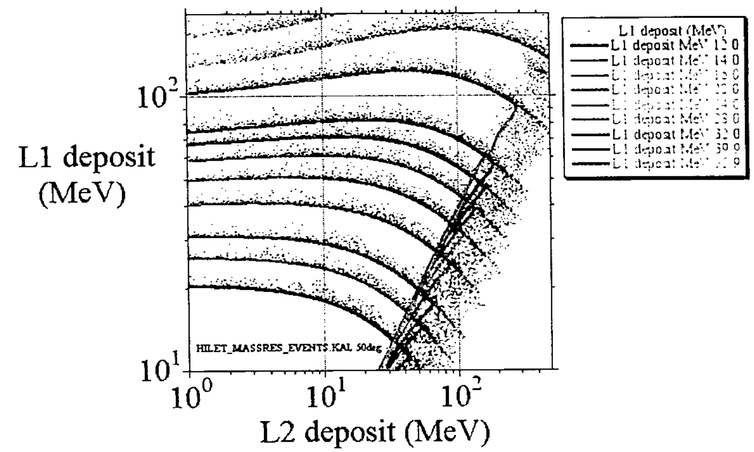
L1 detector hits

L2 detector hits



Trajectories of valid L1L2 coincidences

HiLET - Simulated Response



Foils for Ion Sensor

- Requirements
  - Light tight to shield L1 detectors from sunlight
  - Thin to minimize low-energy threshold for heavy ions
  - Thermal radiator
  - Conducting exterior
- Specifications
  - 0.3 mil Kapton
  - Vacuum-deposited aluminum on inside surface
  - ITO on outside surface
  - Similar composition & size flown successfully on NASA/Wind

Proton Sensor Detectors 1/3

- HiLET proton telescope uses silicon solid-state detectors designed for a previous NASDA mission
  - D1 & D2 (300 micron + solar blind window); D3 & D4 (1000 micron)
  - Procured by Aerospace from Micron Semiconductor Ltd
  - Mounts & detectors in stock at vendor
  - PO issued 11/2003

Proton Sensor Detectors 2/3

- **D1 & D2 design specification:**
  - **Part number: MSD007-300 Type 7M**
  - **Thickness: 300 ± 15 microns**
  - **Active area: 0.38 cm^2**
  - **Capacitance: 15 pf typical**
  - **Leakage current at full depletion: 5 nA typical 20 nA maximum**
  - **Alpha resolution (FWHM): 30 keV**
  - **Full depletion voltage: 50 V maximum**
  - **Operating voltage: FD to 2x FD**
  - **Ohmic window: 20000 angstrom solar blind Al**
- **Number required for flight: 2**
- **Number of spares: 2**

Proton Sensor Detectors 3/3

- **D3 & D4 design specification:**
  - **Part number: MSD008-1000 Type 2M**
  - **Thickness: 1000 ± 50 microns**
  - **Active area: 0.5 cm^2**
  - **Capacitance: 22 pf typical**
  - **Leakage current at full depletion: 100 nA typical 200 nA maximum**
  - **Alpha resolution (FWHM): 30 keV**
  - **Full depletion voltage: 250 V maximum**
- **Number required for flight: 2**
- **Number of spares: 2**

Detector Tally

Detector Type	# flight	# spares	Total	# mounts (ordered separately)
L1	5	6	11	32
L2	1	2	3	6
L3	2	3	5	8
D1 & D2	2	2	4	
D3 & D4	2	2	4	

- Total of 12 detectors for flight
- Total number of active pixels = 35

Electronics

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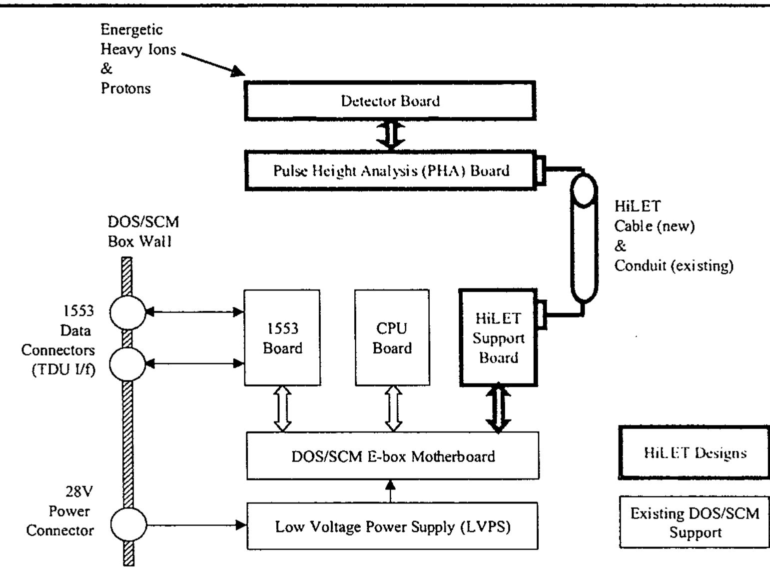
Overview

- Functional Requirements
- Signal Processing
- Detector Interface
- Event Data Processing
- CPU Interface
- In-flight Diagnostic Capabilities
- Board Designs
- Power Supply Margins
- Parts
- Summary

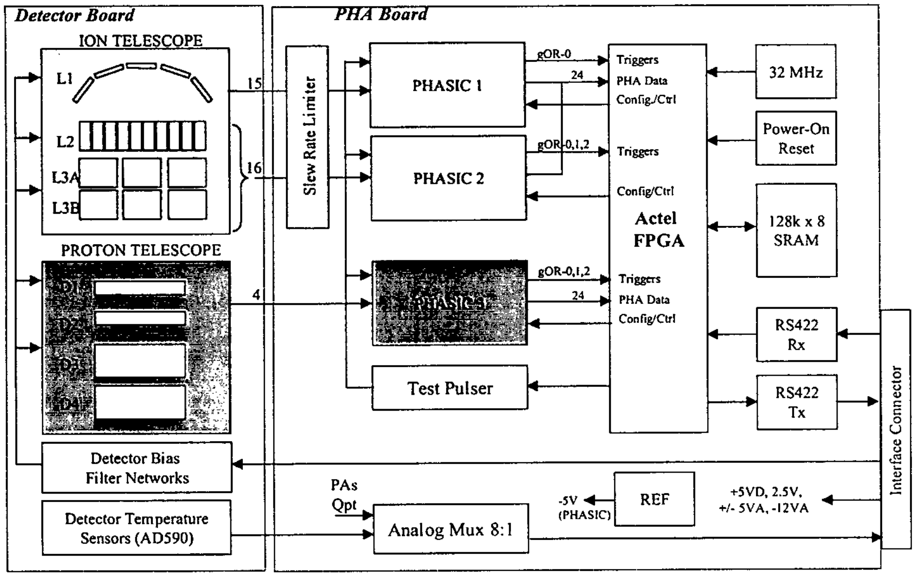
Functional Requirements

- Provide a pulse-height analysis system for a 31-element Heavy Ion Telescope and 4-element Proton Telescope
  - Leverage CalTech PHASIC hybrids
  - Satisfy E-range, resolution, threshold, and rate requirements
  - Implement coincidence logic for filtering background
- Provide in-flight diagnostic capabilities
- Provide a bus interface to DOS/SCM CPU
- Generate detector bias voltages
- Operate on 5VD, +/-5VA, and +/-12VA power sources

Functional Block Diagram



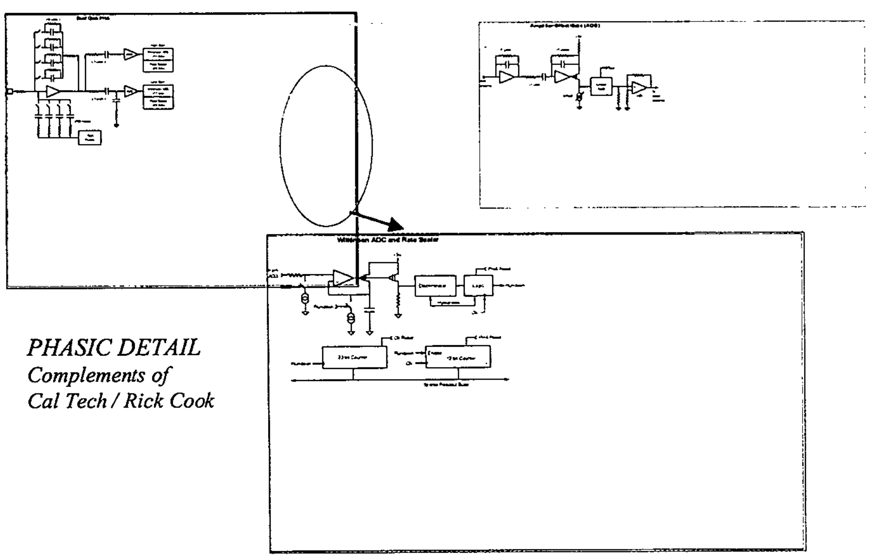
Signal Flow Diagram



PHASIC Hybrid (1/2)

- PHASIC (Pulse Height Analysis System Integrated Circuit) designed by R. Cook, Cal. Tech.
- PHASIC heritage – NASA / ACE and STEREO
- Optimized for large signals, low power, and operational flexibility
  - 16 PHA signal chains
  - Preamplifiers can be tuned for various signal amplitude ranges, detector leakage currents, and input capacitance via serial command
  - High Gain and Low Gain Shaping amplifiers with 11-bit ADC for combined dynamic range of 10,000 (full scale / threshold)
  - 10-bit programmable low-level thresholds via serial command
  - 23-bit singles counter for each high and low gain PHA channel

PHASIC Hybrid (2/2)



PHASIC DETAIL
Complements of
Cal Tech / Rick Cook

Ion Telescope Signal Processing

PHASIC configured in low gain mode will satisfy requirements for heavy ion energy range, low energy threshold, and resolution.

Measurement Requirement	Electronics Requirement	PHASIC Baseline Configuration
Maximum E-Range 70 MeV/n	•Up to 600 MeV in L1 detector •Up to 4 GeV in L2 and L3 detectors	•Low gain channels only •PHASIC Emax = 5.3 GeV •5pF<Cf <75 pF (5 pF steps) •L1 → Cf = 10 pF → 706 MeV •L2, L3 → Cf = 60 pF → 4.2 GeV
Low E-Threshold = 3 MeV/n	•Trigger on L1 energies > 6 MeV	•1.2 to 42 MeV threshold range L1 •9.3 to 276 MeV threshold L2 •Programmable AOG I-offset current source (10-bits)
Mass resolution = 0.5 amu	•On the order of 10 MeV	•11-bit ADC dominates resolution •~ 2 MeV for low gain only

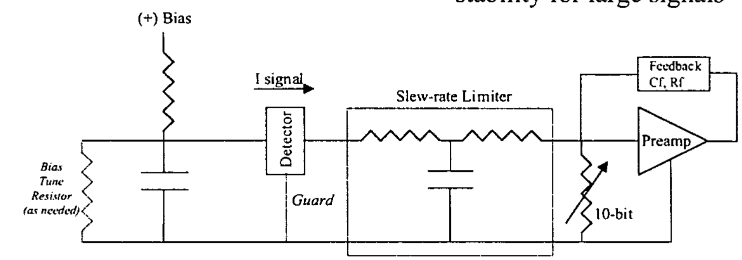
Proton Telescope Signal Processing

PHASIC configured in high gain mode will satisfy requirements for proton/alpha particle energy range and low energy threshold for electron data.

Measurement Requirement	Electronics Requirement	PHASIC Configuration
Expected maximum E-Range 20 MeV protons; retain capability for alphas	•Max deposit in D1 and D2 detectors = 27 MeV •Max deposit in D3 and D4 detectors = 54 MeV for alpha particle margin	•High gain channels only •PHASIC Emax = 265 MeV •5pF<Cf <75 pF (5 pF steps) •D1, D2 → Cf = 10 pF → 35.4 MeV •D3, D4 → Cf = 15 pF → 53.1 MeV
Low E-Threshold = 500 keV for electrons	•Trigger on D1 energies above 500 keV	•~200 keV to 2 MeV threshold •Programmable I-offset current source (10-bits)

Detector Interface (1/2)

- Detectors are DC coupled
- Leakage current compensation provided by PHASIC 10-bit programmable shunt resistance
- Positive detector bias
- Tuning resistor selected as needed to set detector bias; adds minimal power and noise
- Positive input signals
- Slew-rate limiting improves linear response and preamp stability for large signals



Detector Interface (2/2)

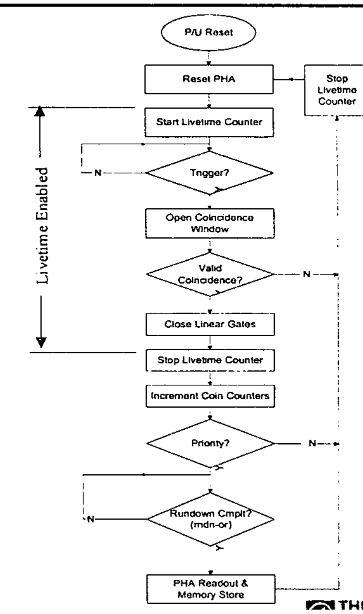
- Two bias supply circuits used to meet various detector depletion voltage requirements
  - Thick detectors are biased from 300V self-resonating supply used on FM1 Dosimeter.
  - Thin detectors are biased from low voltage multiplier circuit.
- Supply ranges & maximum loads estimated for worst-case detector leakage current and include added loading for shunt tuning resistance.

Detector Type	Detector Bias Range	Bias Supply Range	Max Load (uA) Idet + Ires	Bias Supply Max load (uA)
L1	10V - 20V	11V - 34V	7.5	100
L2	10V - 20V	11V - 34V	20	100
L3A, L3B	200V - 230V	200V - 300V	21	50
D1, D2	50V - 100V	50V - 100V	44	100
D3, D4	200V - 250V	200V - 300V	21	50

Event Processing (1/2)

- Dedicated FPGA logic performs event capture & readout @ 32 MHz
- Parallel event processing
- 24-bit Livetime counters for ion and proton sensors at 125 ns resolution
- Rate goal of 10 kHz is met

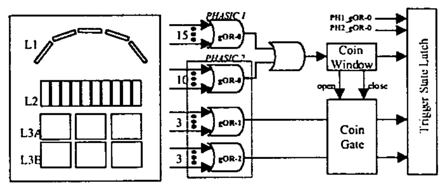
Rate Budget	Deadtime
ADC_{PHASIC}	64 usec
$Readout_{FPGA}$	12 usec
Total	76 usec



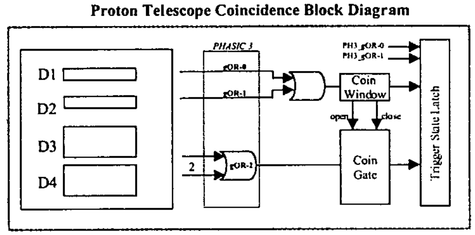
Event Processing (2/2)

- Programmable coincidence window (32 ns to 10 us)
- Heavy ion logic
  - $L1 * L2 * \overline{L3A} * \overline{L3B}$
  - $L1 * L2 * L3A * \overline{L3B}$
  - $L1 * L2 * L3A * L3B$
  - $\overline{L1} * L2 * L3A * \overline{L3B}$
  - $\overline{L1} * L2 * L3A * L3B$
- Proton logic
  - $D1 * D2 * \overline{(D3+D4)}$
  - $\overline{D1} * D2 * (D3+D4)$
  - $D1 * D2 * (D3+D4)$
- Direct event data (raw PHASIC data) stored if prioritizer accepts event
- 24-bit singles rates from PHASIC

Ion Telescope Coincidence Block Diagram



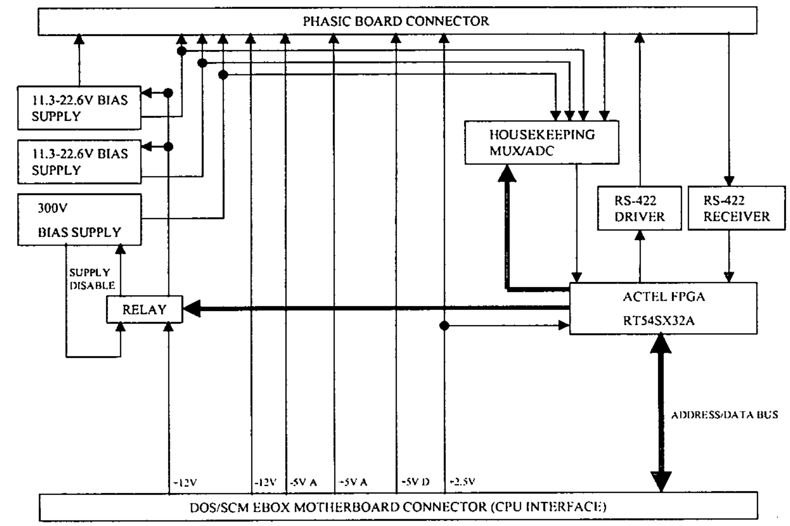
Proton Telescope Coincidence Block Diagram



(Delay blocks not shown)

CPU Interface

HiLET Support Board Block Diagram



In-flight Diagnostic Capabilities

- Test pulser adequately covers heavy ion and proton energy ranges (675 keV to 2.6 GeV)
- Dedicated heavy ion / proton detector temperature monitors
- Dedicated PHA board temperature monitor
- Detector leakage current monitoring provided by DC detector coupling and PHASIC preamplifier test output pin
- On/Off control of detector biases

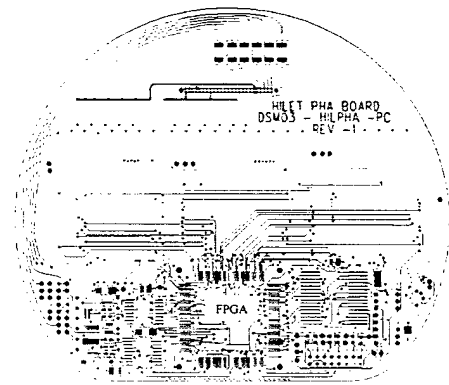
PHA Board Description (1/2)

- Actel RT54SX72 includes event processing, coincidence logic, livetime counters, PHASIC control, matrix scalars, and Tx/Rx data interface
  - Module utilization is 43%
- Test pulser circuit consists of analog multiplexer to select one of four reference levels and is driven by op-amp
- Analog conditioning for temperature monitors and detector leakage current measurements
- Slew-rate limiter networks provide stabilization and improved large signal linearity of preamp; located near PHASIC inputs

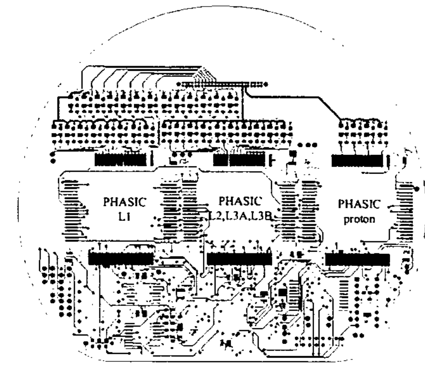
PHA Board Description (2/2)

- Designed in accordance to MIL-STD-275
- Fabricated in accordance to MIL-STD-55110
- 10-Layer FR4-polyimide board ; 0.093 in.
  - Components placed on top and bottom of board
  - Both surface mount and through-hole components are used
- Pigtail harness between PHA board and DOS/SCM chassis
- No blind solder joints

PHA Board Layout



Layer 1 - Top Side



Layer 10 (Bottom side)

Top layer – Digital components / signals / detector bias
Layer 2 – AGND and DGND split plane
Layer 3 – Detector signals / analog power / V reference
Layer 4 – AGND and VDD split plane
Layer 5 – Digital signals

Layer 6 – Digital signals
Layer 7 – AGND and VDD split plane
Layer 8 – Digital signals
Layer 9 – AGND and DGND split plane
Bottom layer – PHASICs / detector signals

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Detector Board Description

- Designed in accordance to MIL-STD-275
- Fabricated in accordance to MIL-STD-55110
- Samtec connectors interface rigi-flex detector mounts and serve as interconnect to PHA board
- Two AD590 temperature sensors located near Heavy Ion "L1" and Proton "D" detector mounts
- Includes detector bias-tuning resistors and filter capacitors
- 6-layer FR4-polyimide printed circuit board
- No blind solder joints

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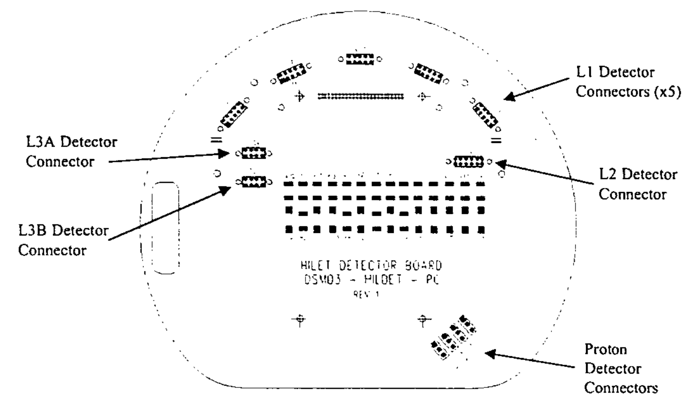
Detector Board Layout



Top layer – Components / Detector Ground / Bias
Layer 2 – Ground
Layer 3 – Detector Signals
Layer 4 – Ground
Layer 5 – Detector Signals
Bottom Layer –Ground

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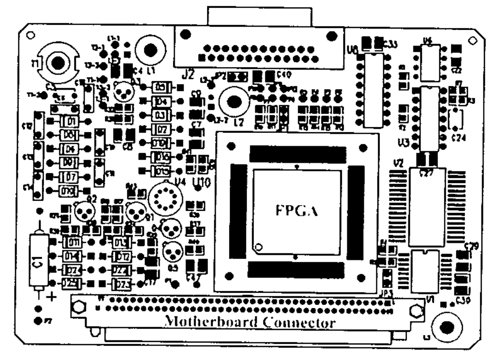
HiLET Support Board

- RT54SX32 device provides a memory-mapped CPU interface for HiLET
  - Module utilization is 50%
- Controls serial RS422 Tx/Rx interface to PHA board
- Supplies Thick/Thin detector biases with On/Off control
- Digitizes analog housekeeping
- 8-layer printed circuit board
  - Conforms to existing DOS/SCM E-box mechanical requirements and Motherboard electrical interface
- No blind solder joints

HiLET Support Board Layout



Top Silkscreen

Power Supply Margin

Added current demand has no impact on LVPS design

HiLET Board Name	5VD	+5VA	-5VA	+12VA	-12VA
	mA	mA	mA	mA	mA
DPU boards & SCM	380	380	73	73	103
HiLET Detector Board	0	0	0	0	0
HiLET PHA Board	204	98	21	0	12
HiLET Support Board	108	0	0	4	0
Total Estimate	692	478	94	77	115
LVPS NTE	2400	650	650	625	625

Grounding

- Grounding scheme is the same as FM1
- S/C 28-volt return is isolated from LVPS secondary grounds by greater than 100 Meg-ohms
- LVPS secondary returns are common at motherboard, are connected electrically to the chassis, and are routed as Analog ground and Digital ground to boards
- HiLET detector returns are routed to the PHA board PHASIC ground pins and are locally isolated from chassis

Electronic Parts (1/2)

- HiLET parts program conforms to FM1 standards
- All microcircuits procured to MIL-STD-883B as a minimum; most are QML class V
- No commercial grade or plastic parts
- PHASICs screened to hybrid class H
- All diodes and transistors are JANTXV or better
- Capacitors and resistors are Class S
- Radiation tolerant parts are used throughout
  - 100 krad minimum hardness
  - PHASICs are tolerant to 12 krads and spot shielded for 10 year life
  - No latchup
  - SEU < 1 bit error in 10 years

Electronic Parts (2/2)

PHA Board Part Types

QTY	PART NUMBER	DESCRIPTION	MANUFACTURER
2	CDR06BXXXXAKWS	CAPACITOR	KEMET
21	CDR33BXXXXAKWS	CAPACITOR	KEMET
35	CDR32BXXXXAKUS	CAPACITOR	KEMET
6	CWR11KHXXXKB	CAPACITOR	KEMET
1	C0805AXXXF2GAC	CAPACITOR	KEMET
1	JANTXV1N4150-1	DIODE	ACI
96	M55342K06BXXXDS	RESISTOR	S.O.T.A.
6	M55342K09BXXXDS	RESISTOR	S.O.T.A.
1	5962R9666301VXC	HS26C31RH	INTERSIL
1	RT54SX72S-1CQ208	PHA_FPGA	ACTEL
3	PHASIC	PHASIC	CAL TECH
1	HX6228TBFT	HX6228 SRAM	HONEYWELL
1	5962R9665101VXC	CD4051BKMS	INTERSIL
1	SFM-125-03-S-D	CONNECTOR	SAMTEC
1	AD590LF/883B	AD590LF TEMP XDCR	ANLG_DEVIC
1	AD558TD/883B	AD558TD DAC	ANLG_DEVIC
1	CD40106BKMSR	CD40106B	HARRIS
1	5962R9568901VXC	HS26C32RH	INTERSIL
1	AD584TH883B	AD584 REFERENCE	ANALOGDEV
1	MCM4800-1M	OSCILLATOR	QTECH

Detector Board Part Types

QTY	PART NUMBER	DESCRIPTION	MANUFACTURER
10	SM20B223K102A/M	HV CAPACITOR X7R 1KV	KEMET
1	SQW-106-01-L-D	CONNECTOR	SAMTEC
1	SQW-104-01-L-D	CONNECTOR	SAMTEC
1	CLT-104-01-G-D	CONNECTOR	SAMTEC
1	TFM-125-02-S-D	CONNECTOR	SAMTEC
4	ESS-103-G-03	CONNECTOR	SAMTEC
5	SQW-105-01-L-D	CONNECTOR	SAMTEC
18	M55342K09BXXXDS	RESISTOR	S.O.T.A.
2	AD590LF/883B	AD590LF TEMP XDCR	ANLG_DEVIC

Support Board Part Types

QTY	PART NUMBER	DESCRIPTION	MANUFACTURER
2	M39003/10-2544S	CAPACITOR	KEMET
30	CDR33BX104AKWS	CAPACITOR	KEMET
1	CCR05CG331FS	CAPACITOR	KEMET
6	CDR32BX103BKWS	CAPACITOR	KEMET
1	CKR06BX105KS	CAPACITOR	KEMET
2	CDR32BX103BKWS	CAPACITOR	KEMET
1	CCR05CG152FS	CAPACITOR	KEMET
1	CDR32BP101BJWS	CAPACITOR	KEMET
16	JANTXV1N4938-1	DIODE	MICROSEMI
4	JTXV1N4150-1	DIODE	MICROSEMI
1	JTX1N5527B-1	DIODE	MICROSEMI
1	RM222-080-201-0256	CONNECTOR	AIRBORN
1	M83513/19-D01NP	CONNECTOR	GLENAIR
4	JANTXV2N2222A	TRANSISTOR	MICROSEMI
1	JANTXV2N3700	TRANSISTOR	MICROSEMI
33	M55342K06BXXXS	RESISTOR	SOTA
1	5962R9666301VXC	HS26C31RH	INTERSIL
1	HX6228TBFT	HX6228 SRAM	HONEYWELL
1	AD537SD/883B	AD537SD V/F	ANLG_DEVICES
1	M39016/29-058M	ER422 RELAY	TELEDYNE
1	AD712TQ/883B	AD712 OP AMP	ANLG_DEVICES
1	5962R9665101VXC	CD4051BDMS	INTERSIL
1	5962R9568901VXC	HS26C32RH	INTERSIL
1	RT54SX32S-1CQ208B	ACT_HILET	ACTEL

Parts Derating (1/2)

- NASA PPL-21 de-rating factors used as a guideline in assessing SSAL class A designs
- De-rated parameters from manufacturer's maximum operating specifications
- The following parts comply fully with PPL-21 guidelines
  - Microcircuits power consumption and output current in compliance
  - Capacitor voltage de-rating in compliance
  - Resistors power consumption and voltage derating in compliance
  - Diodes PIV, surge current, and forward current derating in compliance
  - Transistors power, current, and voltage derating in compliance
  - Relay load current in compliance
- HiLET connectors slightly exceed de-rating guideline
  - See next chart

Parts Derating (2/2)

- PHA I/F connector voltage exceeds derating guideline
  - **Part Type:** Glenair 25-pin micro-miniature connector
  - **Discrepancy:** DWV is 900 volts AC at sea-level; Derated maximum is 225 volts; HiLET maximum voltage is 300 volts DC on this connector
  - **Justification**: Use as is; operate 300 volt supply only in vacuum; HiLET voltage is DC
- Detector board interface connector voltage exceeds derating guideline
  - **Part Type:** Samtec SFM/TFM style connectors
  - **Discrepancy**: DWV is 1050 volts AC at sea-level; Derated maximum is 262 volts; HiLET maximum voltage is 300 volts on this connector
  - **Justification**: Same as above

Summary

- Heavy Ion Telescope leverages STEREO development and meets requirements
- Proton Telescope meets requirements using PHASIC chip
- Good resource margin in FPGAs
- No critical parts issues

TWINS-ES FM2
Flight Software Modifications for HiLET

Dan Mabry
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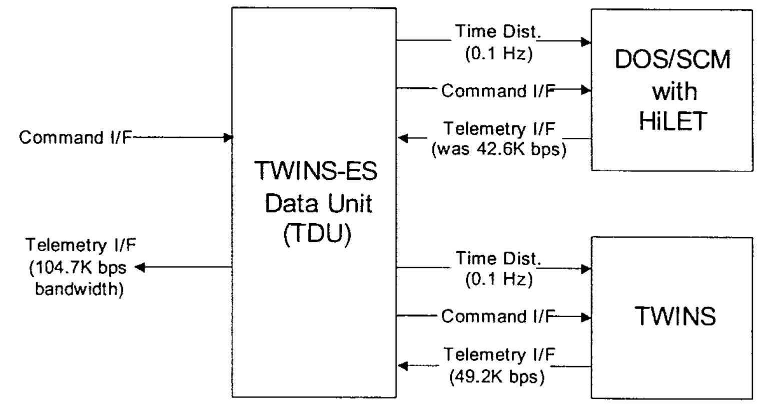
TWINS-ES Software Elements & Interfaces



TDU Software Modifications (FM2)

- HiLET support (commands, telemetry)
  - Added HiLET 1553 subaddress for telemetry passage
  - Added 402 bytes/second HiLET telemetry
  - Commands added to support HiLET calibration
  - HiLET configuration changes rely on existing memory load features
- Perigee data products and packets for HiLET, LAD, and SCM
- TDU software modifications were verified with simulators for HiLET and TWINS prior to delivery

HiLET Telemetry Packet

HiLET Data Packet Contents

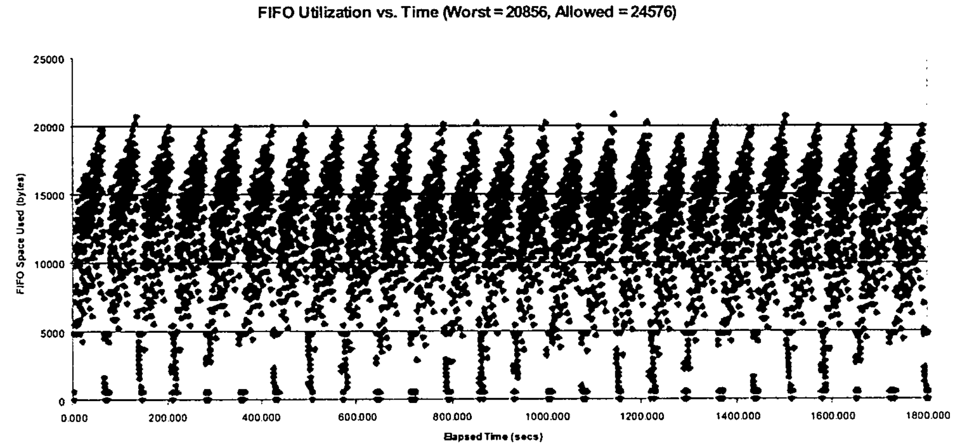
Start Byte Number	Data Element	# of Bytes
1	Primary Header	6
7	Secondary Header	6
13	D1-D4 (proton) singles data (msb first)	12
25	L1 (heavy ion) singles data, 15 detectors	45
70	L2, L3A/L3B singles data, 16 detectors	48
118	Coincidence rates (Dx, Lx)	18
136	Livetime rates (Dx, Lx)	6
142	Matrix Rates	33
175	Number of valid direct events	1
176	Direct event storage	226
402	Checksum	

Packet transmitted once per second
Telemetry requirement = 3.24K bps

TDU Perigee Data Processing

- Real-time data from TWINS and DOS/SCM parsed and stored according to hard-coded algorithms
- New hardware memory buffer in TDU FM2 provides 3 hour ring-buffer storage for selected datasets
  - HiLET: all data stored (10800 packets @ 1 sec res.)
  - TWINS/LAD: all data stored (600 packets / 3 hrs)
  - SCM: 1 HVstep-anode value per 5 msecs (5714 pkts / 3 hrs)
- Ring buffers are maintained throughout orbit
- One ground command causes dump of ring buffer data
- Idle interface times are used for perigee data transfer; real-time data has highest priority for telemetry transmission

TDU Telemetry Bandwidth Assessment



Telemetry bandwidth simulations performed for all TDU, TWINS, and DOS/SCM data sources for a 30 minute period show that all data is successfully output, along with perigee data and HiLET packets, while staying safely below the 24.5K byte FIFO limit.

DOS/SCM Software Reqs. (from FM1)

- Perform stepping control of SCM high voltages. Collect, compress timestamp, and telemeter SCM data packets to TDU
  - Collection/stepping interval is 5 msecs
  - Data generation rate is 41.68 Kbits/second
  - Stepping tables are stored in EEPROM
- Receive, validate and process ground commands and memory loads from TDU (spacecraft)
- Build and transmit housekeeping packets once per second
- Maintain TDU-synchronized time

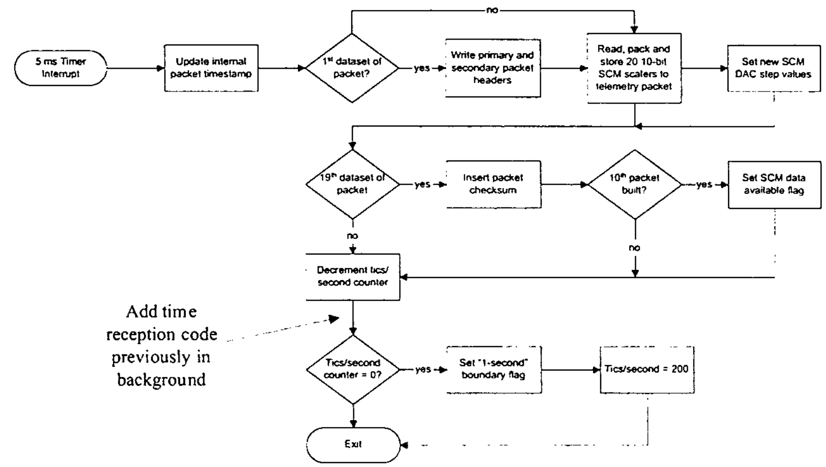
New HiLET Software Requirements

- Add readout and control support for the HiLET sensor
- Augment TDU/1553 architecture to include new HiLET data packets
- Provide non-volatile storage for HiLET look-up table (64K bytes) and configuration information (~320 bytes)

DOS/SCM Software Architecture

- Software design uses a single hardware interrupt (5 msec) – same as FM1 architecture
- Interrupt uses
  - Defines integration interval for SCM data collection and high voltage stepping
  - Derives time intervals for HK output and HiLET data collection
  - New in FM2, is used to receive time broadcast from the TDU to maximize time correlation between DOS/SCM and TDU
- Background task modified to incorporate HiLET data processing on 1-second boundaries

DOS/SCM 5ms Interrupt Service Routine



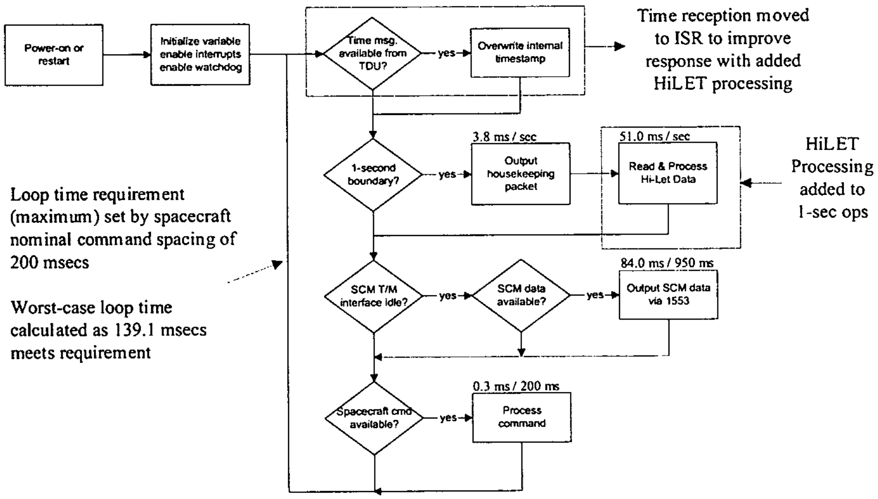
Direct Event Selection Algorithm

- Telemetry space allocated for direct event (DE) storage is 226 bytes per second
- Direct event double-buffer maintained in HiLET support board
  - Stores 226 bytes for direct event storage
  - Events are tagged as either protons or electrons
- Three-pass data selection algorithm
  - First pass: traverse data buffer selecting "programmed minimum" of proton events
  - Second pass: traverse data buffer filling output with heavy ion data
  - Third pass: put any remaining proton events into telemetry buffer

HiLET Processing Impact

- Coding is complete on HiLET direct event processing code
- Calculations performed with assumptions as follows
  - All events received are 7 bytes in length
  - Minimum number of protons for output is 5
  - 700 events of each type are received from support PCB
  - All events must be checked to locate a "small" event
- Result shows execution time of direct event processing is 51 msecs per second
  - Calculations show CPU is 39.2% utilized with HiLET added

DOS/SCM Main Program Loop



Loop time requirement (maximum) set by spacecraft nominal command spacing of 200 msecs

Worst-case loop time calculated as 139.1 msecs meets requirement

HiLET Memory Resources

Memory Type & Contents	Space Required (bytes)	Space Available (bytes)
EEPROM		
HiLET lookup table	65,536	
PHASIC-1 configuration	106	
PHASIC-2 configuration	106	
PHASIC-3 configuration	106	
HiLET test pulser data	3	
Total EEPROM	65,857	158,910
SRAM		
Telemetry buffers	804	
Code space (estimated)	8,192	
Total SRAM	8,996	48,707

DOS/SCM FM2 (w/ HiLET) Summary

- Modified DOS/SCM flight software to support HiLET addition is feasible
  - Adequate memory resources are available
  - Adequate processing and timing margins to handle the additional HiLET burden are shown by detailed coding and calculation
  - The ground station command database requires definition of a few HiLET calibration-related commands
  - HiLET reconfiguration is performed by existing memory load features of the DOS/SCM
  - HiLET telemetry demands fit within the existing TWINS-ES spacecraft interface
- Modified TDU flight software to support HiLET addition is complete and has passed functional testing

Test Plan

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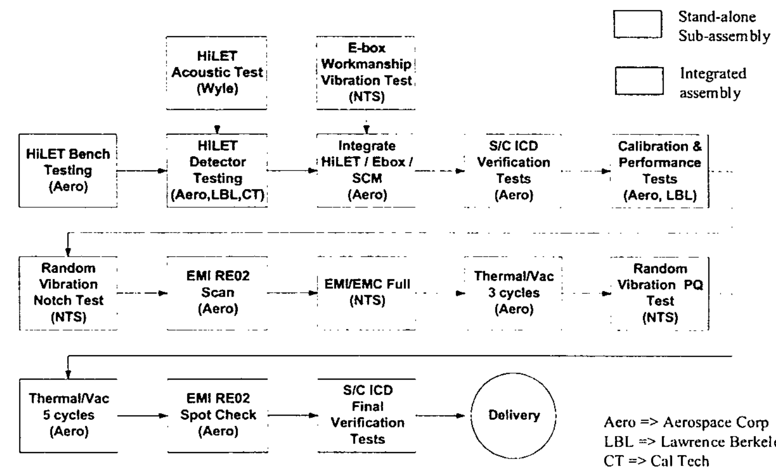
Test Sequence



Aero => Aerospace Corp
LBL => Lawrence Berkeley Lab
CT => Cal Tech
Wyle => Wyle Labs
NTS => National Technical Systems

Random Vibration Tests

- Notch characterization test will validate structural model
- E-box will be screened at MIL-STD-1540 minimum workmanship levels for one minute on normal axis (and lateral if necessary) prior to integration with HiLET
- Integrated instrument will be tested to proto-qualification levels on three axes (3dB above program acceptance levels) with notching
- Instrument will be un-powered during vibration
- Functional test will be performed before and after vibe
- Executed at NTS

Acoustic Test

- External detector/foil assemblies warrant acoustic test
- Proto-qualification test will be performed on the HiLET assembly
  - Two minute duration
  - No SCM or E-box
  - Flight-like L1 detectors and foils installed
  - Unpopulated PCBs installed

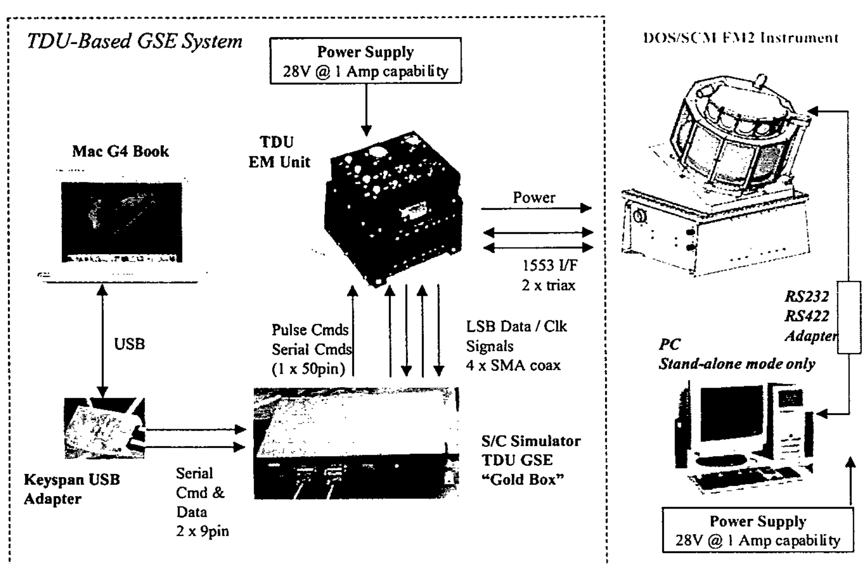
EMI / EMC Tests

- Initial radiated emissions test, s/c bus leakage test, and final spot check performed in Aerospace Labs screen room
- Radiated emissions verified at beginning and end of environmental testing
- Susceptibility testing and formal radiated emissions test performed at NTS

Thermal Vacuum Test

- Split test (3 cycles / 5 cycles) gives early detection of workmanship problems
- Test temperatures will incorporate 10-degree margins on analytical hot and cold predictions
- Survival soak at instrument design limit and pre-test soak time incorporated
- Functional test performed at Hot/Cold on each cycle
- Performed at Aerospace

GSE Configuration (1/2)



GSE Configuration (2/2)

- TDU-based GSE
  - DOS/SCM & HiLET integrated testing
  - Used throughout environmental test flow
  - Functional and EMC tests
  - Final calibration
- HiLET Stand-alone GSE
  - Initial checkout of HiLET electronics
  - Detector testing

Functional Tests (1/2)

- Comprehensive Test Procedure
  - Validates housekeeping monitors
  - Telemetry & commands
  - Flight software (DPU modes, uploads, macros, etc.)
  - SCM high voltage/thresholds/counts/data
  - HiLET detector biases/thresholds/counts/data
- Performed at critical points throughout environmental testing
- Utilizes both automated and manual checkpoints
  - STOL script-driven GSE automatically checks telemetry

Functional Tests (2/2)

- Data is stored in GSE computer as raw telemetry and can be replayed for 100% historical record
- All commands and out-of-spec items are logged in GSE computer
- Test times and results are logged in DOS/SCM Log Book
- Formal reports written for ICD verification test items

Project Programmatics

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HiLET Programmatics

- Status & milestones
- Risk assessment

Status/Milestones

- Structural analysis completed
- Thermal analysis completed
- Mechanical & electrical designs completed
- Test plan developed
- Long-lead parts either on order or in-house

Board Status

		Status					
Instrument	Boards	Design	Layout	Fabrication	Traveler & Parts Kitting	Assembly	Test
HiLET	PHASIC Chip Test	X	X	X	X	X	Feb-04
HiLET	PHA	X	Jan-04	Jan-04	Jan-04	Feb-04	Mar-04
HiLET	Support	X	Jan-04	Jan-04	Feb-04	Feb-04	Feb-04
HiLET	Detector	Jan-04	Feb-04	Feb-04	Feb-04	Feb-04	Feb-04
DOS/SCM System	Mother Board	X	Feb-04	Feb-04	Feb-04	Feb-04	X
DOS/SCM System	CPU	X	X	X	X	X	X
DOS/SCM System	1553 Interface	X	X	X	X	X	X
DOS/SCM System	Low Voltage Power Supply	X	X	X	X	X	X
SCM	Anode	X	X	X	X	X	X
SCM	Support	X	X	X	X	X	Jan-04
SCM	High Voltage Stepper	X	X	X	X	X	Jan-04
SCM	High Voltage Static	X	X	X	X	X	Jan-04

X = Complete

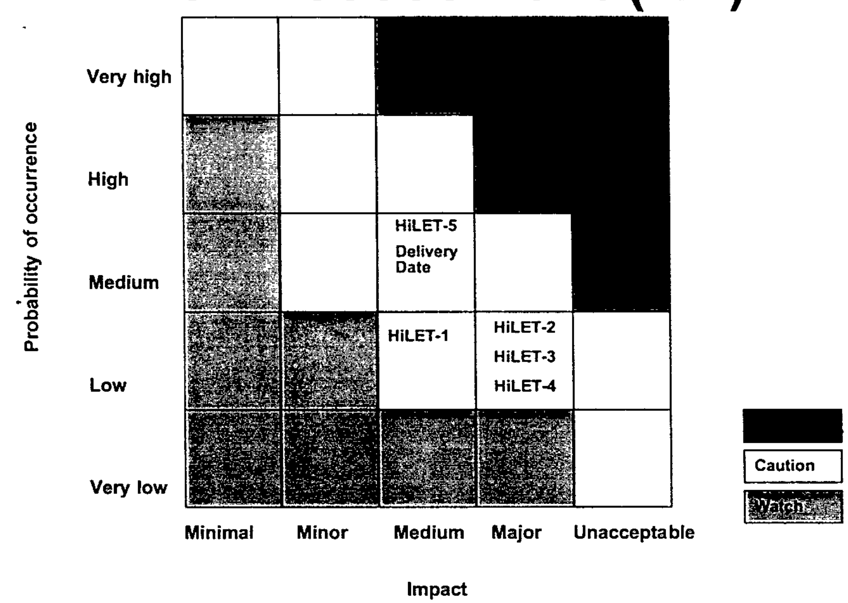
Long-Lead Parts Status

- HiLET solid state & proton detectors
  - Estimated delivery 3/15/04
- ACTEL gate arrays
  - Delivered 1/04

Risk Assessment (1/2)

Item	Risk	Risk Type	Impact	Probability	Mitigation
HiLET - 1	Mass will grow beyond allocation	Technical	Medium	Low	Make instrument smaller by decreasing number of detectors
HiLET - 2	Instrument violates EMI spec	Technical	Major	Low	EMI awareness incorporated into design from the start
HiLET - 3	Dynamic amplification factor (Q) much larger than assumed in structual analysis	Technical	Major	Low	Determine Q in early notch characterization test
HiLET - 4	~50% of L3 detectors for STEREO (same design & manufacturer as for HiLET) found to have unacceptable leakage currents.	Technical	Major	Low	Early detector screening.
HiLET - 5	Detectors delivered behind schedule	Schedule	Medium	Medium	Regular contact with Micron. Borrow spare detectors from CIT for beginning of HiLET test program.
Delivery Date	Backlog in machine shop	Schedule	Medium	Medium	Submit drawings early. Use external shop as needed.

Risk Assessment (2/2)



Closing Remarks

Joe Mazur

Summary

- As part of DOS/SCM FM2, the proposed HiLET design will provide ion measurements for
  - Improving decades-old environmental models
  - Support of solar array design
  - Improving SEE specification & prediction
- Structural & thermal analyses complete
- Thorough test plan, including notch characterization
- Detectors are the only long-lead items
- Risk items identified and tracked
- Ready to build HiLET flight hardware